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EVALUATION OF Be-38% Al ALLOY

Final Report

Report No. 8

27 June 1964 to 28 February 1965

by

Raymond W. Fenn, Jr., W. C. Coons, Donald D. Crooks,
Alfred S. Neiman, John Robinson, Glenn H. Watts

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28 February 1965

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ABSTRACT

Detailed studies were made on six heats of Be-38% Al alloy in the annealed temper to determine the level and reproducibility of mechanical properties, the microstructural features, preferred orientations, and the general metallurgical quality of the metal. Data reported include: Young's modulus, tensile, compressive, shear, bearing and bend properties at temperatures between -320 and 800° F; tensile properties at 75° F after exposure to 400 or 800° F for 10, 100, and 1000 hr; representative photomicrographs; and pole figures [viz: Be (0002), Be $(10\bar{1}1)$ and Al (111)]. Average longitudinal properties at 75°F for the material studied are as follows:

	E (10^6 psi)	C.Y.S. (ksi)	T.Y.S. (ksi)	T.S. (ksi)	Elong. (%)
Extrusions	28.2	41.7	44.5	56.5	6.7
Sheet	29.2	34.2	36.6	50.4	8.1

Mechanical property data are summarized in Tables I and II.

INTRODUCTION

In March 1964, the Materials Sciences Laboratory of the Lockheed Missiles & Space Company Palo Alto, California introduced a new series of Be-Al alloys (Ref. 1) specifically designed for use in missiles and spacecraft. These new alloys have the advantages of unalloyed beryllium (e.g., high Young's modulus and low density), but have significantly improved bend ductility when compared to unalloyed beryllium (Refs. 2 and 3). These new alloys have better weldability and fabricability than unalloyed

beryllium and can be machined, punched, sheared and worked with conventional shop tools without the necessity for the chemical etch following working operations ordinarily required for unalloyed beryllium.

On 27 June 1964, the Materials Division of the Propulsion and Vehicle Engineering Laboratory of NASA's George C. Marshall Space Flight Center initiated this program to evaluate the Be-38% Al alloy as commercially produced and to determine whether the quality and reproducibility of this alloy were adequate for vehicle use. To this end three heats of sheet, 0.060-in.-thick, and three heats of extrusions, 3/16-in. x 2 1/2-in. bar, in the annealed condition were purchased by LMSC from the Beryllium Corporation of America in Reading, Pa.

Table I

SUMMARY OF MECHANICAL PROPERTIES FOR Be-38% Al EXTRUSIONS
(Annealed temper, 3/16-in. × 2-1/2-in. bar; Strain rate: ~0.005/min to yield, ~0.08/min to failure)

Test Temperature:			-320° F				75° F				400° F				800° F			
Heat Number:			21-33	21-32	21-35	3 Heat Avg.	21-33	21-32	21-35	3 Heat Avg.	21-33	21-32	21-35	3 Heat Avg.	21-33	21-32	21-35	3 Heat Avg.
Mechanical Properties																		
E	(10^6 psi)	L					$29.9^{16(a)}$	27.4^3	27.4^3	28.2	31.0^2	–	–	31.0	16.1^3	15.8^3	15.8^4	15.9
		T					–	–	–	–	–	–	–	–	–	–	–	–
F_{tu}	(ksi)	L	68.8^3	68.6^3	72.5^3	70.0	57.0^3	58.1^3	54.4^3	56.5	41.9^3	43.4^3	46.2^3	43.8	28.9^3	29.4^3	30.8^3	29.7
		T	57.3^3	58.3^3	63.2^3	59.6	46.0^3	46.1^3	46.8^3	46.3	38.8^3	39.0^3	41.5^3	39.8	25.8^3	25.4^3	27.4^3	26.2
F_{ty}	(ksi)	L	50.4^3	50.3^3	53.1^3	51.3	44.5^3	44.9^3	44.2^3	44.5	37.8^3	38.1^3	39.8^3	38.6	24.5^3	24.7^3	26.0^3	25.1
		T	42.1^3	47.1^3	49.6^3	46.3	42.1^3	42.2^3	43.1^3	42.5	38.2^3	37.5^3	39.1^3	38.3	24.1^3	24.2^3	26.7^3	25.0
F_{cy}	(ksi)	L					41.8^3	39.4^3	43.8^3	41.7	36.2^3	34.2^3	35.6^2	35.3	13.7^3	14.9^3	15.4^3	14.7
		T					41.3^3	39.6^3	43.5^3	41.5	35.6^3	36.2^3	36.4^3	36.1	11.9^3	12.0^3	11.7^3	11.9
$F_{0.7\ sec\ yield}$	(ksi)	L					33.2^3	33.7^3	36.8^3	34.6	34.6^2	29.8^2	33.8^2	32.9	11.5^2	12.8^2	12.6^2	12.3
		T					30.8^3	23.9^3	31.9^3	28.9	32.9^2	33.0	32.9	32.9	10.4^2	10.7^2	10.0^2	10.4
F_{su}	(ksi)	yz-z(c)					35.4^3	35.8^3	39.2^3	36.8	26.0^2	26.1^3	27.1^2	26.4	12.7^2	12.2^2	13.4^2	12.8
		yz-y					39.5^3	39.2^3	43.6^3	40.8	29.1^3	28.2^2	29.7^2	29.0	13.9^2	13.7^2	14.8^2	14.1
		xz-z					27.3^3	24.3^3	28.1^3	26.6	21.8^2	22.2^2	24.0^2	22.7	11.8^2	12.0^2	12.0^2	11.9
		xz-x					29.6^3	28.8^3	29.0^3	29.1	23.0^2	23.6^2	25.2^2	23.9	12.5^2	12.7^2	13.4^2	12.9
F_{bru}	(ksi) e/D = 2	L					89.6^3	91.2^3	93.5^3	91.5	69.9^2	70.0^2	76.6^2	72.2	36.2^4	34.6^2	36.9^4	35.9
	3/16-in. pin	T					87.1^3	90.8^3	99.7^3	92.5	70.0^2	72.5^2	69.2^2	70.6	30.2^2	32.6^2	34.2^4	32.3
F_{bry}	(ksi) e/D = 2	L					80.1^2	79.3^3	78.5^3	79.9	64.9^2	64.0^2	68.6^2	65.8	31.2^2	32.2^2	33.6^2	32.3
		T					74.0^3	75.8^3	86.4^3	78.7	58.8^2	61.9^2	69.2^2	63.3	28.6^2	30.5^2	31.8^2	30.3
Bend	(deg)(b)	L	30^2	31^2	31^2	31	36^2	42^2	35^2	38	22^2	20^2	27^2	23	600° F			
Angle		T	15^2	12^2	14^2	14	9^2	8.5^2	8.5^2	9	7^2	6^2	7^2	7				
e	(%)	L	2.2^3	2.7^3	2.8^3	2.6	7.6^3	7.3^3	5.1^3	6.7	7.2^3	8.6^3	9.2^3	8.3	4.2^3	4.1^3	3.7^3	4.0
		T	1.9^3	2.0^3	2.4^3	2.1	2.5^3	1.2^3	0.7^3	1.5	2.5^3	2.5^3	2.1^3	2.4	1.9^3	1.7^3	1.9^3	1.8
R.A.	(%)	L	2.5^3	2.8^3	2.8^3	2.8	7.4^3	6.8^3	5.4^3	6.5	9.0^3	10.2^3	11.2^3	10.1	9.0^3	8.8^3	10.1^3	9.3
		T	1.3^3	1.2^3	1.5^3	1.5	2.0^3	3.5^3	2.6^3	2.7	3.0^3	2.9^3	2.8^3	2.9	3.3^3	2.0^3	3.2^3	2.8

(a) Exponents = number of tests
(b) Nominal thickness 0.054 in.

(c) Shear plane:
xz = longitudinal
yz = transverse

Shear direction:
x = longitudinal
y = long transverse
z = short transverse

Table II

SUMMARY OF MECHANICAL PROPERTIES FOR Be-38% Al SHEET
(Annealed temper, 0.060-in. thick; Strain rate: ~0.005/min to yield, ~0.08 to failure)

Test Temperature:			-320° F				75° F				400° F				800° F			
Heat Number:			21-30	21-31	21-34	3 Heat Avg.	21-30	21-31	21-34	3 Heat Avg.	21-30	21-31	21-34	3 Heat Avg.	21-30	21-31	21-34	3 Heat Avg.
Mechanical Properties																		
E	(10^6 psi)	L					28.2^{6}	29.5^{7}	29.8^{3}	29.2	30.4^{3}	27.1^{3}		28.8	16.5^{3}	16.6^{3}	17.5^{3}	16.9
		T					29.4^{6}	28.5^{6}	29.4^{3}	29.1	28.6^{3}	31.6^{3}		30.1	18.0^{3}	16.5^{3}	17.0^{3}	17.2
F_{tu}	(ksi)	L	60.1^{3}	56.5^{3}	63.6^{3}	60.1	51.3^{3}	45.9^{4}	54.0^{3}	50.4	38.8^{3}	37.8^{3}	40.4^{3}	39.0	23.2^{3}	24.0^{3}	25.7^{3}	24.3
		T	58.6^{3}	52.9^{3}	64.8^{3}	58.8	51.9^{5}	48.4^{4}	52.5^{3}	50.9	39.5^{3}	38.1^{3}	41.6^{3}	39.7	23.3^{3}	23.4^{3}	25.5^{3}	24.1
F_{ty}	(ksi)	L	41.0^{3}	40.4^{3}	43.9^{3}	41.8	36.2^{5}	34.9^{4}	38.6^{3}	36.6	30.7^{3}	29.4^{3}	32.5^{3}	30.9	19.7^{3}	20.8^{3}	22.5^{3}	21.0
		T	43.0^{3}	40.0^{3}	46.3^{3}	43.1	35.4^{5}	34.6^{4}	38.3^{3}	36.1	30.7^{3}	30.0^{3}	33.1^{3}	31.3	20.1^{3}	20.1^{3}	21.9^{3}	20.7
F_{cy}	(ksi)	L					34.0^{3}	32.1^{3}	36.6^{3}	34.2	27.6^{2}	25.6^{2}	29.8^{2}	27.7	14.3^{2}	13.2^{2}	14.6^{2}	14.0
		T					33.4^{2}	32.9^{3}	36.6^{3}	34.3	27.2^{2}	27.2^{2}	30.8^{2}	28.4	14.5^{2}	13.5^{2}	15.1^{2}	14.4
$F_{0.7\ sec}$ yield	(ksi)	L					22.9^{3}	22.2^{3}	25.7^{3}	23.6	24.1^{2}	21.8^{2}	25.7^{2}	23.9	11.4^{2}	11.0^{2}	13.2^{2}	11.9
		T					24.5^{3}	22.4^{3}	28.4^{3}	25.1	22.4^{2}	23.6^{2}	26.8^{2}	24.3	12.6^{2}	11.2^{2}	13.2^{2}	12.3
F_{su}	(ksi)	yz-z(c)																
		yz-y					27.7^{2}	25.7^{2}	28.1^{2}	27.2	21.2^{2}	21.0^{2}	22.4^{2}	21.5	10.1^{2}	10.7^{2}	11.5^{2}	10.8
		xz-z																
		xz-x					25.8^{2}	27.2^{2}	28.0^{2}	27.0	21.4^{2}	20.6^{2}	22.8^{2}	21.6	10.4^{2}	10.4^{2}	11.3^{2}	10.7
F_{bru}	(ksi) e/D = 2 3/16-in. pin	L					94.8^{2}	93.6^{3}	100.9^{3}	96.4	65.3^{2}	65.1^{2}	73.3^{2}	67.9	32.5^{2}	33.7^{2}	38.2^{2}	34.8
		T					94.8^{3}	95.2^{3}	97.0^{3}	95.7	63.6^{2}	64.8^{2}	72.2^{2}	66.9	30.8^{2}	30.8^{2}	33.9^{2}	31.8
F_{bry}	(ksi) e/D = 2	L					62.0^{2}	63.5^{3}	72.8^{3}	66.1	54.1^{2}	53.2^{2}	59.2^{2}	55.5	27.5^{2}	29.5^{2}	32.2^{2}	29.7
		T					66.0^{3}	68.6^{3}	74.0^{3}	69.5	52.8^{2}	54.0^{2}	58.0^{2}	54.9	28.8^{2}	29.4^{2}	32.4^{2}	30.2
Bend	(deg)(b)	L	32^{2}	29^{2}	22^{2}	28	48^{2}	45^{2}	38^{2}	44	$\{28^{2}$	22^{2}	24^{2}	$25\}$				
Angle		T	31^{2}	32^{2}	33^{2}	32	46^{2}	37^{2}	34^{2}	39	$\{38^{2}$	24^{2}	24^{2}	$29\}$	600° F			
e	(%)	L	2.3^{3}	2.3^{3}	2.5^{3}	2.4	10.8^{3}	6.2^{4}	7.4^{3}	8.1	9.4^{3}	11.8^{3}	10.5^{3}	10.6	5.8^{3}	3.9^{3}	5.2^{3}	5.0
		T	2.0^{3}	3.8^{3}	2.7^{3}	2.8	9.6^{5}	7.1^{4}	7.8^{3}	8.2	12.0^{3}	11.8^{3}	11.9^{3}	11.9	7.4^{3}	4.4^{3}	4.8^{3}	5.5
R. A.	(%)	L	2.5^{3}	2.2^{3}	2.4^{3}	2.4	8.4^{3}	6.2^{4}	7.4^{3}	7.3	13.1^{3}	16.5^{3}	10.7^{3}	13.4	12.1^{3}	9.0^{3}	11.2^{3}	10.8
		T	3.2^{3}	2.6^{3}	2.5^{3}	2.8	10.4^{5}	7.2^{4}	8.2^{3}	8.6	15.8^{3}	15.9^{3}	12.1^{3}	14.6	13.8^{3}	10.8^{3}	9.1^{3}	11.2

(a) Exponents = number of tests
(b) Nominal thickness 0.054 in.

(c) Shear plane:
xz = longitudinal
yz = transverse

Shear direction:
x = longitudinal
y = long transverse
z = short transverse

SUMMARY OF EXPERIMENTAL RESULTS

Mechanical properties obtained at various temperatures between - 320 and 800° F are summarized for extrusions and sheet in Tables I and II, respectively. Variations in properties are extremely small, e. g., standard deviations on T. Y. S. range from 0. 8 to 2. 0 ksi (see page 18). Variations from heat to heat are shown graphically in the plots of average properties per each heat versus temperature (see Figs. 1 through 19). Variations in properties from specimen to specimen can be readily seen in the data tabulations (Tables III through XXIV) for each property.

The extrusion properties show some anisotropy, although the compressive yield strength is isotropic at 75 and 400° F. By contrast, the sheet is remarkably isotropic in all respects except 400° F Young's modulus.

Prolonged exposures for times up to 1000 hr at 400 and 800° F show no apparent effect on the 75° F tensile properties of the sheet or extrusions (Figs. 6 through 11).

Detailed microstructural studies were made on six heats of metal to determine the reproducibility of the microstructure, the nature of any defects found, and the reasons for eertain anomalous test results. Photomicrographs are presented (Figs. 26 through 30) to show representative microstructures and the nature of the defects observed.

Quantitative preferred orientation studies were made to provide pole figures [e. g., Be (0002), Be $(10\bar{1}1)$ and Al (111)] for each heat of extruded and rolled alloy (Figs. 31 through 48).

DISCUSSION

Experimental Material

Three heats of Be-38% Al extrusions and three heats of Be-38% Al sheet in the annealed temper were purchased from The Beryllium Corporation in Reading, Pa. The extrusions were 3/16 by 2-1/2-in. bar with rounded corners; the sheet was nominally 0.060-in. thick by 12 in. or more wide. Materials used in this program were as follows:

		As Received Condition			
Form	Designation	Annealed	Ground	Etched	Al (%)
Extrusion	21-33-4A	o	o	o (Light)	—
Extrusion	21-33-5A	o	o	o (Light)	—
Extrusion	21-33-5B	o	o	o (Light)	37.2
Extrusion	21-32-2A	o	o	o (Light)	—
Extrusion	21-32-8	o	o	o (Light)	37.0
Extrusion	21-35-307	o	o		—
Extrusion	21-35-309	o	o		36.9
Sheet	21-30-3B	o	o		—
Sheet	21-30-3C	o	o		38.1
Sheet	21-30-3D	o	o		—
Sheet	21-31-2A	o	o	o (Heavy)	—
Sheet	21-31-2B	o	o		38.1
Sheet	21-31-2C	o	o	o (Heavy)	—
Sheet	21-34-300A	o	o		36.1
Sheet	21-34-303B	o	o		—

The designations consist of two parts. The first four digits indicate the heat number, while the following digits and letters indicate a particular extrusion or sheet. Numbers added behind these designations are test specimen serial numbers arbitrarily assigned at the time the raw material was cut into specimen blanks. Chemical analyses for

aluminum were made by an independent testing laboratory, Testing and Controls, Inc., in Mountain View, California. A portion of the material was etched by the vendor as indicated above for the purpose of revealing surface defects. All specimens were tested with as-received surfaces, without chemical treatment by LMSC, except for bend specimens which were etched to a common thickness for comparison purposes.

Young's Modulus

Extrusions. Young's moduli for extrusions are summarized by heat in Table I, detailed by test in Table III, and shown graphically in Fig. 1. Moduli at 75° F varied from a minimum of 27.4×10^6 psi to a maximum of 30.8×10^6 psi between various specimens in different heats, with an average value for three heats of 28.2×10^6 psi. At 300, 400 and 500° F, the modulus increased to $\sim 31 \times 10^6$ psi in agreement with data previously published by Fenn, et al. (Ref. 2). Because this increase in modulus at intermediate temperatures has now been observed on several heats of material, this behavior is believed to be real.

Sheet. Young's modulus values for sheet are summarized by heat in Table II, detailed in Table IV, and plotted in Fig. 1. At 75° F, the modulus varies from a minimum 27.7×10^6 psi to a maximum of 30.5×10^6 psi between specimens, with an average value of 29.1×10^6 psi for 3 heats (31 tests) with the longitudinal and transverse values being essentially equal. At 400° F, the moduli showed some tendency to be higher than at 75° F; however, the increase in modulus was not consistent with respect to direction. At 800° F, the moduli between heats varied by about 1.0×10^6 to 1.5×10^6 psi with an average of 17×10^6 psi, or 58% of the 75° F value.

Tensile Properties

Extrusions. The tensile properties of extrusions at -320, 75, 400 and 800° F are summarized in Table I, detailed in Tables V, VI, VII and VIII, and plotted as a function of temperature in Fig. 2 and 3. It is significant to note from these figures that the tensile strength of extruded Be-38% increases 19 to 29% on decreasing the temperature

from 75 to -320° F. while unalloyed beryllium decreases on the order of 30% as shown by Jacobson (Ref. 4). Upon increasing the temperature from 75 to 800° F, the longitudinal tensile strength gradually decreases to ~ 30 ksi while the transverse T.S. decreases to ~ 26 ksi. It should be noted here that in testing the transverse extrusion specimens at 75° F, some of the specimens failed before the strain rate could be increased. To avoid this problem at 400 and 800° F, the transverse extrusion specimens were deliberately tested without increasing the strain rate beyond 1% strain. Although the slow strain rate probably results in lower T.S. values, a better check on the reproducibility of the alloys is obtained.

The tensile strength at 75° F shows a maximum of 59.2 and a minimum of 53.7 ksi in the longitudinal direction, and 50.7 and 44.8 ksi in the transverse direction. The average T.S. values show a maximum heat-to-heat variation of ~ 4 ksi longitudinally and ~ 1 ksi transversely with an anisotropy of ~ 8 to 12 ksi.

The tensile yield strength at 75° F varies from a maximum of 45.2 to a minimum of 43.8 ksi in the longitudinal direction and from 45.0 to 41.1 ksi in the transverse direction. Maximum variation in average T.Y.S. from lot to lot is 1 ksi, and the maximum anisotropy is 2.5 ksi, with the longitudinal values being higher than the transverse. At -320° F the anisotropy is approximately 5 ksi, somewhat higher than at 75° F, as is the scatter. Some of the differences between the longitudinal and transverse properties at -320° F, which might appear to be anisotropy, may be a consequence of testing specimens cut from different extrusions (see Table V) because of material limitations. At 400 and 800° F, the T.Y.S. is essentially isotropic.

Percent elongation at 75° F varies from 4.6 to 8.6 in the longitudinal direction and 0.6 to 2.6 in the transverse direction. The average values for three lots were 6.7 and 1.5 for the longitudinal and transverse directions, respectively. An optimum in the elongation temperature curve was obtained at 400° F (Fig. 2).

Reduction-in-area data show similar trends to percent elongation. It is noteworthy that 40% of the reduction in area occurs in the thickness direction of Be-38% Al

extrusions with 60% in the width direction, in direct contrast to unalloyed beryllium which shows negligible reduction in the thickness direction. This ability of Be-Al to deform in the short transverse direction probably accounts for the significantly better bendability of the alloy compared to unalloyed beryllium. Tensile stress-strain curves for extrusions at -320, 75, 400 and 800°F are given in Figs. 20 and 21.

Sheet. The tensile properties of sheet at -320, 75, 400 and 800°F are summarized in Table II, detailed in Tables IX, X, XI and XII, and presented graphically in Figs. 4 and 5.

The sheet is essentially isotropic at 75, 400 and 800°F, while showing very slight anisotropy with respect to T. S. at -320°F. The range of T. Y. S. at 75°F varies from 39.0 to 33.7 ksi while the T. S. varies from 54.5 to 41.8 ksi. However, it should be pointed out that specimens 2C-5 and 2C-6 (heat 21−31), which had low T. S. (41.8 and 42.3 ksi) and low elongations (~ 3%), both had deep transverse surface scratches resulting from severe grinding in the vendor's surface-finishing operation. The vendor has now modified the grinding procedure to eliminate this source of defects. Without eliminating the test results from these two specimens, average values for T.Y.S., T.S. and elongation vary a maximum of 3.7 ksi, 9.1 ksi, and 4.4%, respectively, as illustrated in Figs. 4 and 5. By eliminating the test results from the defective specimens, the average T.S. varies only 4.2 ksi from heat to heat.

Percent elongation shows an optimum (of ~ 11%) around 400°F, similar to the longitudinal extrusion data. The reduction-in-area data follow the elongation data closely except at 800°F where the reduction in area values are approximately double the elongation values. This behavior, which is noted for both the sheet and extrusions, indicates that the deformation is essentially uniform at -320, 75, and 400°F but somewhat localized at 800°F. Significantly, at room temperature 50% of the reduction in area occurs in the thickness direction whereas, in beryllium, essentially no thinning of the sheet occurs according to Klein et al. (Ref. 5). Tensile stress-strain curves for sheet at -320, 75, 400, and 800°F are given in Fig. 24.

Elevated Temperature Exposure Effects

The effect of elevated-temperature exposure on Be-38% Al alloys was evaluated by exposing duplicate longitudinal extrusion specimens and duplicate longitudinal and transverse sheet specimens to 400 and 800° F for 10, 100 and 1000 hr and comparing the 75° F tensile results to those of unexposed control specimens.

As shown in Tables XIII and XIV and Figs. 6 through 11, there was no apparent deviation from the 75° F tensile properties as a result of exposure at 400 and 800° F for times up to 1000 hr on either sheet or extrusion. While certain differences exist between the "zero-exposure" control specimens and the 10-hr exposure points, in no case is there significant variation from 10 through 1000 hr. Therefore, the apparent variations (i. e., heat 21–31 T. Y. S., heat 21–35 T. S.) are attributed to statistical scatter in the control specimen data.

Calculations based on diffusion data produced on Contract AF 33(657)-11225, now underway at LMSC, indicate that no interdiffusion would occur in Be-38% Al alloy at 800° F even at times over 8000 hr, indicating the long-term phase stability in this alloy.

Compression Properties

Compression Yield Strength. The C. Y. S. of extrusions and sheet at 75, 400 and 800° F are summarized in Tables I and II, detailed in Table XV and XVI, and shown graphically in Figs. 12 and 13.

For extrusions, the compressive yield stress is essentially isotropic at 75 and 400° F, but at 800° F the longitudinal values average ~ 3 ksi higher than the transverse values. At 75° F, the average compressive yield strength of 41.6 ksi is 1 ksi lower than the transverse T. Y. S. and 1.8 ksi lower than the longitudinal T. Y. S. The maximum C. Y. S. obtained was 45.1 ksi and the minimum was 38.0 ksi for a maximum specimen-to-specimen variation of 7.1 ksi, while the heat-to-heat averages varied by a maximum of 4.4 ksi. The compression stress-strain curves are plotted in Figs. 22 and 23.

For sheet, the compressive yield strength is isotropic at 75, 400 and 800° F. Again at 75° F, the compressive yield strength is about 2 ksi lower than the tensile yield at 75° F. The maximum C. Y. S. observed on sheet at 75° F is 37.7 ksi and the minimum is 32.1 ksi, for a maximum specimen-to-specimen variation of 5.6 ksi. The maximum variation from heat to heat is 4.5 ksi. Compression stress-strain curves are plotted in Fig. 25.

0.7 Secant Yield Stress. The 0.7 secant yield stress values were obtained by putting a line having a slope which is 0.7 of Young's Modulus through the origin of the load-strain curve and calculating the stress at the intersection of the line and the load-strain curve. These data, presented in Tables I, II, XVII, and XVIII, are not considered a good indication of the quality or reproducibility of alloys because the values obtained are extremely sensitive to extensometer performance, small strain errors, and the quality of the load-strain curves whereas these factors generally do not affect the compression yield strength values to the same extent. Consequently, the most reliable 0.7 secant yield stress values are considered to be the three heat averages which are listed in ksi below:

	Direction	75° F	400° F	800° F
Extrusions	L	34.6	32.9	12.3
Extrusions	T	28.9	32.9	10.4
Sheet	L	23.6	23.9	11.9
Sheet	T	25.1	24.3	12.3

Shear Properties

The shear strength properties are summarized in Tables I and II, detailed in Tables XIX and XX and plotted in Figs. 15 and 16. The explanation of shear planes and direction is shown schematically in Fig. 14. In this figure's coordinate system, the yz plane is a transverse plane with the z direction being short transverse and the y direction being long transverse. The xz plane is a longitudinal plane with the x direction the longitudinal direction and the z direction the short transverse direction.

Shear tests were made at 75, 400, and 800°F. Values for 600°F, obtained by interpolation, are also included.

Extrusions. The shear values in the transverse plane, long transverse direction (yz-y), and short transverse direction (yz-z), were markedly higher than values in the longitudinal plane (xz-z and xz-x). Average values for eaeh heat in the transverse plane varied from 35.4 to 43.6 ksi at 75°F, 26.0 to 29.7 ksi at 400°F, and 12.2 to 14.8 ksi at 800°F. Average values for eaeh heat in the longitudinal plane ranged from 24.3 to 29.6 ksi at 75°F, 21.8 to 25.2 ksi at 400°F, and 11.8 to 13.4 ksi at 800°F depending upon the shear direction. Shear strengths within a shear plane vary from 2.5 to 4 ksi at 75°F, but show less variation with increasing temperature.

Sheet. The sheet shear values were almost identical in both the longitudinal plane, longitudinal direction (xz-x) and transverse plane, long transverse direction (yz-y) evincing the isotropie nature of the sheet. Shear strength values averaged for each lot ranged from: ~25.8 to 28.1 at 75°F, 21.0 to 22.8 at 400°F, and 10.1 to 11.5 ksi at 800°F depending upon the shear direetion.

Bearing Strength Properties

Bearing yield strengths and ultimate strengths are summarized in Tables I and II, detailed in Tables XXI and XXII, and plotted in Figs. 17 and 18. The data for extrusions are quite insensitive to directionality with the three heat average showing a 0.7 ksi variation at 75°F increasing with temperature to a 3 ksi variation at 800°F, the longitudinal values being higher than the transverse. As one might expect with the isotropic sheet, the very small direetionality variation was almost identical to the extrusions. The bearing ultimate strength variations were again almost identical to the bearing yield strength variations.

Depending upon the test direction, extrusion bearing ultimate strength based on heat averages varied from 87.1 to 99.7 ksi at 75°F, 69.2 to 76.6 ksi at 400°F and

30.2 to 36.9 ksi at 800° F. Bearing yield strength based on heat averages ranged from 74.0 to 86.4 ksi at 75° F, 58.8 to 69.2 ksi at 400° F, and 28.6 to 33.6 ksi at 800° F, depending upon the test direction.

Sheet bearing ultimate strength based on heat averages ranged from 94.8 to 100.9 ksi at 75° F, 63.6 to 73.3 ksi at 400° F, and 30.8 to 38.2 ksi at 800° F. Bearing yield strength based on heat averages varied from 62 to 74 ksi at 75° F, 52.8 to 59.2 ksi at 400° F, and 27.5 to 32.4 ksi at 800° F depending upon the test direction.

Bend Evaluations

Three-point simple-beam bend tests were made on 1-in.-wide by 2-in.-long specimens using a 0.25-in.-radius mandrel. Because only part of the sheet was received in the etched condition while most of it was in the ground condition, all of the material, both sheet and extrusions, was etched to a thickness of 0.054 in. to allow direct comparison of all of the bend data. The bend test results are summarized in Tables I and II, detailed in Tables XXIII and XXIV, and shown graphically in Fig. 19. The designations, longitudinal and transverse, refer to the specimen axes. The bend axis is at 90 degrees to the designated specimen direction.

Extrusions. Test results shown in Tables I and XXIII and in Fig. 19 indicate that for the test temperature investigated, -320, 75, and 600° F, the bend angle for longitudinal specimens is a maximum 47 deg at 75° F with a three-lot average of 38 deg, a value which is over 500% higher than obtained on extruded unalloyed beryllium. Because the elongation data show optimum values at 400° F, a somewhat higher bend angle might be expected at 300 to 400° F. It is noteworthy that the 31-deg average bend angle at -320° F is higher than the 23-deg average angle obtained at 600° F.

With regard to transverse bend data, on Be-38% Al extrusions, the maximum bend angle is obtained at -320° F; the 14-deg average obtained at this temperature is significantly greater than the 75° F average of 9 deg. This transverse value for Be-38% Al alloy, although relatively low, is even higher than for unalloyed extruded Be in the longitudinal direction which has a 7-deg bend.

Sheet. There was no significant differenee in bend angle between the longitudinal and transverse sheet specimens indicating the isotropic quality of the sheet. A maximum bend angle in the range - 320 to 600° F would be expected at 300 to 400° F. Although there were insufficient data to show this in Fig. 19, previous work at LMSC has shown this to be the case. Again the three heat averages show a ~30-deg bend angle obtained at - 320° increasing to 42-deg at 75° F and decreasing to ~ 27 deg at 600° F.

Metallographic Studies

Representative samples from various locations in the six heats of metal were examined metallographically to determine representative mierostruetures, type of defects, and microstructural uniformity.

Typical microstructures of extruded Be-38% Al alloy in the annealed condition are shown in Fig. 26. These photomicrographs taken on heat 21-33, showing both longitudinal and transverse seetions at 100 magnification, are representative of the relatively clean structures observed in heats 21-33 and 21-32. The gray areas are beryllium and the white areas are aluminum. Small black inelusions noted in this figure have been tentatively identified as beryllium carbide. There is no evidence that these particular inclusions have any significant effeet on the mechanical properties.

Photomicrographs in Fig. 27 show detailed mierostructural features of extruded Be-38% Al in the annealed eondition (heat 21-32) at the higher magnification of 1000×. Figure 27a, the longitudinal seetion, shows the aluminum (white) to be somewhat elongated, while in Fig. 27b (the transverse seetion) the aluminum is essentially randomly disposed.

Typical defects encountered in these studies are illustrated in Figs. 28 and 29. The finely distributed black areas in Fig. 28 are eonsidered to be microporosity arising from the casting operation. This eondition was noted in both extrusions made from lot 21-35, (i. e. , extrusions 307 and 309). Beeause the photomicrographs in Fig. 28 were taken on specimen 307-14 from lot 21-35, the tensile data in Table VI can be

studied for possible effects of this type of defect. It will be assumed that specimens 307-13, -15, -16, and -17 might behave similarly to specimen 307-14. We note that 307-14 and adjacent longitudinal specimens -13 and -15 have about the same T.Y.S., but about 3 to 4 ksi lower T.S. and ~2% lower elongation than the other two heats. The transverse counterparts -16 and -17, show about the same T.Y.S., but ~1 ksi lower T.S. and ~0.6% lower elongation. Although this type of defect is undesirable, it does not appear to be catastrophically detrimental to the mechanical properties of the material.

Photomicrographs in Fig. 29a and b show: a) an area of aluminum segregation occasionally encountered in extruded metal, and b) some severe surface scratches with embedded grit from the vendor's grinding operation. No detrimental effects have been attributed to the aluminum segregation (see Table VI, transverse tensile data for specimen 21-32, 2A-16). The severe transverse surface scratches shown for sheet specimen 2C-5L (heat 21-31) are believed to be a contributing factor in the decreased strength and elongation obtained. In Table X, it will be noted that specimen 2C-5 and adjacent specimen 2C-6 have ~7 ksi lower T.S. and ~6% lower elongation than specimen 2C-10 which was cut out about 3 in. away.

Typical microstructural features of annealed Be-38% Al sheet are shown in Fig. 30 at both low and high magnification. This microstructure is representative of both longitudinal and transverse sections. It will be noted that the sheet has somewhat larger aluminum areas than the extruded material (Figs. 27 through 29).

Preferred Orientation Studies

Eighteen quantitative pole figures – i.e., Be (0002), Be $(10\bar{1}1)$, and Al (111) – were determined on three heats of Be-38% Al extrusions and three heats of Be-38% Al sheet, all in the annealed temper. These data are presented in Figs. 31 through 48.

A quantitative method utilized for determining the pole figures, which was developed at LMSC by Bragg and Packer (Ref. 6), permits making the absorption corrections

which are necessary in working with materials such as beryllium which have low a atomic number.

Basal (0002) pole figures for beryllium are shown in Figs. 31, 32, and 33 for the extruded alloy and in Figs. 34, 35 and 36 for sheet alloy. Pyramidal $(10\bar{1}1)$ pole figures for beryllium, determined in lieu of prism pole figures because of reflection interferences between Be and Al, are shown in Fig. 37, 38, and 39 for the extrusions and in Figs. 40, 41, and 42 for the sheet. Aluminum (111) pole figures are shown in Figs. 43, 44, and 45 for extrusions and in Figs. 46, 47, and 48 for the sheet. Complete pole figures were determined for extrusion heat 21-33 and sheet heat 21-34, and half pole figures were determined on the other heats of metal to determine variations between heats.

The Be (0002) pole figure (Fig. 31) for extruded Be-Al shows a concentration of basal poles at approximately 45 and 90 deg to the transverse direction, each concentration being approximately equal in intensity. Although the pole concentrations at 45 deg to the transverse direction are similar to those reported for extruded unalloyed beryllium by Jacobson (Ref. 4), the pole concentration which is absent in the Be pole figure but present in the center of the Be-Al pole figure make the two pole figures significantly different. The texture is considerably less preferred for the Be-Al than for the Be, the maximum random levels being 4R and 7R, respectively. For sheet, the (0002) poles are concentrated in the center of the pole figure (Fig. 36) and are essentially randomly dispersed about the normal to the sheet surface. The basal pole figures for Be-Al sheet are essentially the same as those reported by Greenspan (Ref. 7) for hot pressed and bi-directionally rolled unalloyed beryllium sheet.

The Be $(10\bar{1}1)$ pyramidal pole figure (Fig. 37) shows a well defined texture for the extruded Be-38% alloy (heat 21-33) with a tendency for the $[10\bar{1}0]$ direction to be aligned with the extrusion direction. This pole figure is similar to the $(10\bar{1}1)$ pole figure reported for magnesium foil by Caglioti and Sachs (Ref. 8). The authors are not aware of any $(10\bar{1}1)$ pole figures for unalloyed beryllium. However, the prism

pole figure $(10\bar{1}1)$ reported by Jacobson (Ref. 4) shows the same tendency for the $[10\bar{1}0]$ direction to align with the extrusion direction. Extrusions from heat 21-32 and 21-35 show $(10\bar{1}1)$ pole figures similar to heat 21-33 but developed to a lesser degree. In the sheet, heat 21-34 shows a more highly developed $(10\bar{1}1)$ texture than the other sheet (heats 21-30 and 21-31) but less well developed than extrusion heat 21-33.

The Al (111) pole figures are essentially the same for both the extruded and rolled alloy and are typical (112)[111] textures. The (111) pole figures for the sheet suggest that heat 21-30 was processed differently than heat 21-31 or 21-34 or that the directional identification of the sheet was inconsistent. Because the sheet is isotropic with respect to its strength characteristic, these properties are of little help in determining inconsistencies in directionality. However, Young's modulus at 400°F does show some anisotropy – e.g., modulus changes from $\sim 28 \times 10^6$ to $\sim 31 \times 10^6$ depending upon the direction – which are in agreement with the preferred orientations shown in Figs. 46 and 47, further adding to the possibility of inconsistant directional identification by the vendor.

Metal Quality

Out of the 730 specimens machined and tested, five were observed to have defects associated with decreased strength levels. These specimens are identified below along with the type of test and the nature of the defect.

Specimen No.	Direction	Type of Test	Nature of Defect
Extrusions			
21-33, 4A-1	L	400°F Tensile	Surface crack
21-35, 307-14	L	75°F Tensile	Microporosity
Sheet			
21-31, 2C-5	L	75°F Tensile	Deep transverse scratches plus non-uniform etching
21-31, 2C-6	L	75°F Tensile	Deep transverse scratches plus non-uniform etching
21-31, 2B-24	L	400°F, 10-hr Exposure	Dross in fracture

Establishing acceptance standards for this alloy would permit rejection of material with some of these defects such as cracks and scratches, minimizing or eliminating their effect on the properties. Since this sheet was purchased, the vendor has instituted improved grinding techniques which have resulted in improved surface finish.

Assuming that exposure to temperatures of 400 and 500° F had no effect on the 75° F tensile properties, all 75°F tensile test results (including those on defective specimens) were used to calculate* estimates of the universe standard deviations for: 1) each heat of metal, 2) three heats of extrusions, and 3) three heats of sheet as shown below.

	T. Y. S. (ksi)				T. S. (ksi)			
	Longitudinal		Transverse		Longitudinal		Transverse	
Heat No.	Avg.	s	Avg.	s	Avg.	s	Avg.	s
Extrusions								
21-33	$44.93^{15(a)}$	0.849	42.12^{3}	0.778	57.17^{15}	0.999	46.05^{3}	0.128
21-32	45.01^{15}	0.541	42.17^{3}	0.925	57.62^{15}	1.474	$46.05^{2(b)}$	0.354
21-35	44.17^{15}	0.772	43.13^{3}	1.666	52.97^{15}	1.481	$50.7^{1(b)}$	—
3 Heats	44.70^{45}	0.809	42.47^{9}	1.142	55.92^{45}	2.488	46.82^{6}	1.854
Sheet								
21-30	35.30^{16}	0.775	35.71^{18}	0.812	50.30^{13}	1.077	51.10^{18}	1.465
21-31	37.78^{15}	1.944	37.40^{17}	2.092	49.00^{15}	3.100	49.22^{17}	1.483
21-34	39.40^{15}	0.542	39.35^{15}	0.619	53.39^{15}	0.410	53.09^{15}	1.275
3 Heats	37.44^{46}	2.40	37.38^{50}	2.00	50.88^{46}	2.702	51.09^{50}	2.088
Excluding defective sheet #2C from heat 21-31								
21-31	38.65^{12}	0.786	38.02^{14}	1.742	50.18^{12}	1.391	49.49^{14}	1.510
3 Heats	37.66^{43}	1.965	37.56^{47}	1.913	51.34^{43}	1.946	$5[illegible].29^{47}$	1.995

(a) Exponents equal number of tests
(b) Specimens run at different strain rate omitted

These data show very low standard deviation values for the tensile yield strength of extrusions, i.e., 0.8 and 1.14 ksi in the longitudinal and transverse directions, respectively. In the sheet, heat 21-30 and 21-34 also had very low T. Y. S. standard deviations, 0.5 to 0.8 ksi. Heat 21-31, which contained deep grinding scratches and

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*Calculated using equation:

$$s = \sqrt{\frac{\sum_{i=1}^{n} X_i^2 - \frac{\left(\sum_{i=1}^{n} X_i\right)^2}{n}}{n-1}}$$

pits at the bottom of the scratches from heavy etching, has a standard deviation of ~2.0 ksi contributing strongly to the three heat standard deviation of 2.4 ksi. Elimination of the data for the defective sheet (2C in heat 21-81), which would automatically occur using standard quality control acceptance procedures, lowers the 3 heat standard deviation to 1.96 ksi. However, either of these values are acceptable and compare favorably with other commonly used aircraft quality alloys, as shown in the following tabulation of standard deviations.

Material	Longitudinal Tests	Longitudinal T.Y.S. (ksi)	Longitudinal T.S. (ksi)	Transverse Tests	Transverse T.Y.S. (ksi)	Transverse T.S. (ksi)
Extrusions						
Be-38% Al-O	45	0.81	2.49	6−9	1.14	1.85
Sheet						
Be-38% Al-O	46	2.40	2.70	50	2.00	2.09
Ti 8-1-1[a] (single anneal)	52	4.55	4.70	55	5.16	4.6
17-7 PH[b] (Stainless steel)	44	3.54	3.65	63	7.18	5.9
6061-T6 (Al)[c]	1648	~4 (estimated from handbook data)				
AZ31B-O (Mg)[c]	1630	~2.7 (estimated from handbook data)				
Block						
Be Block[d]	61	4.2[e]	2.6	130		3.8
	177	2.93[f]	3.5	294		3.83

(a) Ref. 9
(b) Ref. 10
(c) Ref. 11
(d) Ref. 12
(e) Based on 471 tests, both longitudinal and transverse
(f) Based on 190 tests, both longitudinal and transverse

CONCLUSIONS

The reproducibility of mechanical properties from heat to heat of annealed Be-38% extrusions and sheet, as judged by three standard deviations of tensile yield strength, is excellent, being significantly less than some commonly used aircraft quality alloys, e.g., AZ31B-O, 6061-T6, Be, Ti 8-1-1, and 17-7 PH stainless steel.

From -320 to 800°F, the sheet is essentially isotropic with respect to both strength and ductility, while the extrusions show varying degrees of anisotropy depending upon direction, temperature, and the property measured.

Both the sheet and extrusions show significant increases in strength (~9 to 29%) upon decreasing the temperature from 75 to -320°F. At 800°F, the alloys retain ~30 to 59% of their room temperature strength.

Be-Al alloy does not exhibit the poor short transverse ductility of unalloyed Be sheet. The isotropic nature of ductility in Be-Al sheet allows 400% more bendability than in unalloyed Be at 75°F. The lower, but adequate, uniaxial tensile elongations exhibited by Be-Al (as compared to unalloyed Be) are not in this case an indication, as is bendability, of the biaxial ductility so necessary for reliable structural service. The bendability of Be-Al at -320°F is also better than the room-temperature bendability of unalloyed beryllium. This fact, coupled with the significant strength increases at -320°F, make Be-38% Al alloy a candidate material for cryogenic service.

Prolonged exposure for times up to 1000 hr in 400 and 800°F air showed no apparent effect on the room temperature tensile properties of the annealed sheet or extrusions.

RECOMMENDATIONS

A complete evaluation, such as the one conducted under this contract, should now be made on as-extruded and as-rolled Be-38% Al alloy. Such an evaluation would provide data on high strength material (which had only a slight decrease in 75° F ductility) while retaining the desirable high modulus and low density of the annealed metal.

Accurate Young's modulus measurements should be made at -320°F on both the as-processed and annealed alloy similar to measurements already made in the range of 75 to 800°F. Such measurements would require some modification of the existing optical strain measuring system used to obtain accurate modulus values in this program. Compression tests should also be made at -320°F on both as-processed and annealed alloy.

Now that the reliability of mechanical property values has been demonstrated, studies should be made to determine.

- The effect of metallurgical variables on bendability
- Optimum conditions for bending and forming (e.g., temperature, rate, temper)
- Effect of forming operations on residual mechanical property levels
- Development and optimization of joining techniques
- Fracture toughness characteristics compared to competitive materials using impact and slow bend test techniques
- Corrosion characteristics and optimum surface finishing systems

Table III

YOUNG'S MODULUS DATA FOR Be-38% Al EXTRUSIONS
(Annealed Temper – Longitudinal)

Heat No.	Specimen No.	Young's Modulus (10^6 psi) (Room Temperature)					Test Temp. (°F)	Young's Modulus (10^6 psi) (Elevated Temperatures)					
						Avg.							Avg.
21-33	5A-2	30.5	30.5	30.5		$30.5^{3(a)}$	300	33.4	30.8	29.9			31.4^{3}
	5A-6	$29.8^{T(b)}$	28.7^{T}	28.8^{T}	30.1^{T}	29.4^{4}	400	31.9	30.1				31.0^{2}
	5A-6	29.6	29.3			29.4^{2}	–						–
	5A-5	29.0	29.2	28.9		29.0^{3}	500	30.2	36.5	26.9	33.5	28.4	31.1^{5}
	5A-7	30.2	30.8	31.2	30.8	$\underline{30.8^{4}}$	800	14.3	17.3	16.8			16.1^{3}
						29.9^{16}							
21-32	2A-29	27.6	27.2	27.4		$\underline{27.4^{3}}$	800	15.8	15.8	15.8			15.8^{3}
21-35	307-42	27.4	27.0	27.8		$\underline{27.4^{3}}$	800	14.7	16.0	16.5	15.8		15.8^{4}

(a) Exponents = number of tests
(b) T = Strain measured with Tuckerman Optical Extensometers; all others measured with Marten's Optical System

Table IV

YOUNG'S MODULUS DATA FOR Be-38% Al SHEET
(Annealed Temper)

Heat No.	Specimen No.	Direction(a)	Young's Modulus (10^6 psi) (Room Temperature)				Test Temp. (°F)	Young's Modulus (10^6 psi) (Elevated Temperature)			
						Avg.					Avg.
21-30	3B-28	L	27.6	27.6	28.4	27.9^{3}	400	28.9	31.5	30.7	30.4^{3}
	3B-27	L	29.0	28.2	28.5	28.6^{3}	800	16.6	16.5	16.5	16.5^{3}
						28.2^{6}					
	3B-15	T	29.4	28.6	28.9	29.0^{3}	400	27.9	29.4	28.4	28.6^{3}
	3B-16	T	28.9	30.4	30.2	29.8^{3}	800	15.6	18.4	20.1	18.0^{3}
						29.4^{6}					
21-31	2C-3	L	29.4	31.7	30.6 30.2	30.5^{4}	400	26.3	25.1	30.0	27.1^{3}
	2C-4	L	27.7	28.5	29.6	28.6^{3}	800	14.3	17.4	18.2	16.6^{3}
						29.5^{7}					
	2C-1	T	29.5	29.3	28.9	29.2^{3}	400	28.9	33.0	33.0	31.6^{3}
	2C-2	T	27.8	28.2	27.1	27.7^{3}	800	15.1	16.8	17.7	16.5^{3}
						28.5^{6}					
21-34	300A-52	L	29.7	30.0	29.9	29.8^{3}	800	17.4	16.4	18.8	17.5^{3}
	300A-37	T	29.3	30.1	28.8	29.4^{3}	800	17.6	16.1	17.4	17.0^{3}

(a) L = Longitudinal; T = Transverse
(b) Exponents = number of tests

Table V

-320° F TENSILE PROPERTIES FOR Be-38% Al Extrusions

(Annealed temper, ground condition, 3/16-in. × 2 1/2-in. bar.)
Strain rate to 1% strain: ~ .005/min;
Strain rate beyond 1% strain: ~ .07/min.

	Longitudinal					Transverse				
Heat No.	Specimen No.	T.Y.S. No.	T.S. (ksi)	Elong. (%) (a)	R.A. (%)	Specimen No.	T.Y.S. No.	T.S. (ksi)	Elong. (%) (b)	R.A. (%)
21-33	5B-49	50.2	70.0	$2.0^{k(c)}$	2.9	4A-29	44.6	58.9	3.6	2.0
	5B-50	50.2	65.8	2.0^{k}	2.2	4A-30	35.7	55.0	2.3^{k}	0.8
	5B-52	50.8	70.1	$2.5^{og(d)}$	2.3	4A-40	45.9	58.6	1.9	1.2
Avg.		50.4	68.8	2.2	2.5		42.1	57.3	2.6	1.3
21-32	8-8	50.9	71.3	2.8^{k}	2.8	2A-23A	46.0	55.5	2.0^{k}	0.9
	8-7	50.8	69.6	3.0^{k}	2.7	2A-23B	46.4	58.5	2.0	1.7
	8-10	49.8	64.8	$2.3^{sb(e)}$	3.0	2A-34	48.8	60.9	2.0	0.9
Avg.		50.3	68.6	2.7	2.8		47.1	58.3	2.0	1.2
21-35	309-1	52.2	72.6	2.7^{k}	3.3	309-23	46.9	62.9	2.0	1.4
	309-2L	54.9	72.8	2.8^{og}	2.9	307-34	52.6	62.6	2.2	1.9
	309-3L	52.1	72.1	3.0^{sb}	3.1	307-40	49.4	64.9	2.4	2.5
Avg.		53.1	72.5	2.8	3.1		49.6	63.2	2.4	1.9
Avg. for 3 heats		51.3	70.0	2.6	2.8		46.3	59.6	2.1	1.5

(a) 1-in gage length
(b) 1/2-in. gage length
(c) sb = shoulder break
(d) og = broke outside gage length
(e) k = broke under knife edge

Table VI

75° F TENSILE PROPERTIES FOR Be-38% Al EXTRUSIONS
(Annealed temper, ground condition, 3/16-in. x 2-1/2-in. bar;
Strain Rate to 1% strain: ~.005/min;
Strain Rate beyond 1% strain: ~.07/min)

Heat No.	Longitudinal					Transverse				
	Speci-men No.	T.Y.S. (ksi)	T.S. (ksi)	Elong. (%)(a)	R.A. (%)	Speci-men No.	T.Y.S. (ksi)	T.S. (ksi)	Elong. (%)(b)	R.A. (%)
21-33	4A-60	43.8	56.2	6.2	6.0	4A-24	42.8	45.9	2.6	1.3
	5A-10	45.2	57.4	9.0	9.6	4A-54	42.2	46.2	2.4	3.2
	5B-51	44.5	57.5	7.5	6.8	4A-44	41.3	46.1	2.6	1.5
	Avg.	44.5	57.0	7.6	7.4		42.1	46.0	2.5	2.0
21-32	2A-25	45.1	57.5	6.2	6.1	2A-16	41.1	45.8	1.2	3.4
	8-2	44.7	57.7	7.0	6.3	8-5	42.7	>46.0(d)	>1.0og(e)(c)	2.3
	8-33	44.8	59.2	8.6	8.1	8-35	42.7	46.3	1.2	4.8
	Avg.	44.9	58.1	7.3	6.8		42.2	46.1	1.2	3.5
21-35	307-13	44.5	55.5	5.8	6.2	307-16	41.8	44.8	0.6(c)	1.8
	307-14	44.0	53.7	4.9	5.3	307-17	42.6	44.9	0.6(c)	2.3
	307-15	44.0	53.9	4.6	4.8	307-33	45.0	50.7	1.0	3.6
	Avg.	44.2	54.4	5.1	5.4		43.1	46.8	0.7	2.6
Avg. for 3 heats		44.5	56.5	6.7	6.5		42.5	46.3	1.5	2.7

(a) 1-in. gage length
(b) 1/2-in. gage length
(c) Strain rate not increased above 1% strain
(d) Specimen broke in pin hole
(e) og = Specimen broke outside gage lengths

Table VII

400°F TENSILE PROPERTIES FOR Be-38% Al EXTRUSIONS
(Annealed temper, ground condition, 3/16-in. × 2-1/2-in. bar;
Strain rate to 1% strain: ~ 0.005/min; Strain rate beyond 1% strain: ~ 0.07/min)

Heat No.	Longitudinal					Transverse				
	Specimen No.	T.Y.S. (ksi)	T.S. (ksi)	Elong. (%)(a)	R.A. (%)	Specimen No.	T.Y.S. (ksi)	T.S. (ksi)	Elong. (%)(b)	R.A. (%)
21-33	4A-1	38.2	39.1(c)	2.0(d)	3.6	4A-26	39.4	39.4(c)	3.0	2.4
	4A-3	38.0	43.5	9.4	11.0	4A-33	37.4	39.0(c)	2.6	3.3
	4A-6	37.3	43.1	10.2	12.3	4A-58	37.9	38.0(c)	2.0	3.4
	Avg.	37.8	41.9	7.2	9.0		38.2	38.8(c)	2.5	3.0
21-32	8-1	38.0	43.6	7.8	6.6	2A-27	37.8	39.0(c)	2.8	3.8
	8-3	38.3	43.0	7.5	10.2	2A-33	37.5	39.0(c)	2.2	3.2
	8-15	38.1	43.7	10.5	13.7	8-X6	37.3	38.9(c)	2.4	1.6
	Avg.	38.1	43.4	8.6	10.2		37.5	39.0(c)	2.5	2.9
21-35	307-27	39.4	45.5	8.6	11.3	309-6	39.1	40.9(c)	2.0	1.9
	307-30	40.3	46.9	10.6	12.2	309-17	38.5	41.6(c)	2.0	3.2
	307-32	39.8	46.3	8.5	10.2	309-28	39.8	41.9(c)	2.2	3.3
	Avg.	39.8	46.2	9.2	11.2		39.1	41.5(c)	2.1	2.8
Avg. for 3 heats		38.6	43.8	8.3	10.1		38.3	39.8	2.4	2.9

(a) 1 in. gage length
(b) 1/2 in. gage length
(c) 0.01 in./min only
(d) surface crack prior to test

Table VIII

800 F TENSILE PROPERTIES FOR Be-38% Al EXTRUSIONS
(Annealed temper, ground condition, 3/16-in. × 2-1/2-in bar;
Strain rate to 1% strain: ~ 0.005/min; strain rate beyond 1% strain: ~ 0.07/min)

Heat No.	Longitudinal					Transverse				
	Specimen No.	T.Y.S. (ksi)	T.S. (ksi)	Elong. (%)[a]	R.A. (%)	Specimen No.	T.Y.S. (ksi)	T.S. (ksi)	Elong. (%)[b]	R.A. (%)
21-33	4A-59	24.3	28.7	4.2	10.1	4A-32	27.9	29.4[c]	1.8	2.3
	5A-9	24.5	28.8	4.6	7.8	4A-52	23.3	25.0[c]	2.4	5.5
	5A-11	24.8	29.2	3.8	9.2	4A-53	21.0	23.0[c]	1.4	2.0
	Avg.	24.5	28.9	4.2	9.0		24.1	25.8[c]	1.9	3.3
21-32	2A-24	24.7	29.2	3.7	6.9	2A-17	24.1	25.3[c]	1.8	2.8
	2A-26	25.0	29.5	4.6	8.9	2A-23C	24.1	25.2[c]	1.6	2.2
	8-11	24.3	29.6	4.1	10.5	2A-28	24.4	25.6[c]	1.6	1.0
	Avg.	24.7	29.4	4.1	8.8		24.2	25.4[c]	1.7	2.0
21-35	309-7A	25.4	30.4	4.0	10.5	309-4	24.8	26.8[c]	2.0	3.3
	309-18	25.4	30.4	3.7	9.3	309-29	27.6	27.8[c]	1.8	2.7
	309-X7	27.2	31.7	3.5	10.6	307-39	27.6	27.6[c]	1.8	3.5
	Avg.	26.0	30.8	3.7	10.1		26.7	27.4[c]	1.9	3.2
Avg. for 3 heats		25.1	29.7	4.0	9.3		25.0	26.2	1.8	2.8

(a) 1-in. gage length
(b) 1/2-in. gage length
(c) 0.01-in./min only

Table IX

-320° F TENSILE PROPERTIES FOR Be-38% Al SHEET
(Annealed temper, 0.060-in. thick)
Strain rate to 1% strain: ~0.005/min; strain rate beyond 1% strain: ~0.08/min

Heat No.	Longitudinal					Transverse				
	Specimen No.	T. Y. S. (ksi)	T. S. (ksi)	Elong. (%)[a]	R. A. (%)	Specimen No.	T. Y. S. (ksi)	T. S. (ksi)	Elong. (%)[a]	R. A. (%)
21-30	3B-8	40.3	56.9	2.0[og]	2.8	3B-30	41.9	59.0	2.0[og]	3.0
	3B-9	40.8	60.3	2.0[og]	2.2	3B-31	43.7	59.4	2.0[sb]	3.0
	3B-10	41.9	63.1	3.0[og]	2.6	3B-33	43.4	57.5	2.0[k]	3.5
	Avg.	41.0	60.1	2.3	2.5		43.0	58.6	2.0	3.2
21-31	2C-7	40.4	59.7	2.8	2.3	2C-22	39.9	50.1	3.2[og]	2.3
	2C-8	42.4	53.4	2.0	1.9	2C-23	39.9	54.7	4.1[og]	2.8
	2C-9	38.4	56.5	2.2	2.4	2C-24	40.1	53.8	4.2[og]	2.7
	Avg.	40.4	56.5	2.3	2.2		40.0	52.9	3.8	2.6
21-34	303B-4	44.1	62.7	2.1	1.9	303B-X2	45.8	60.4	2.0[og]	2.7
	303B-24	44.1	62.4	2.4	1.8	303B-13	46.8	66.8	3.5[og]	2.2
	303B-25	43.6	65.6	3.1	3.4	303B-14	46.4	67.1	2.5[k]	2.5
	Avg.	43.9	63.6	2.5	2.4		46.3	64.8	2.7	2.5
Avg. for 3 heats		41.8	60.1	2.4	2.4		43.1	58.8	2.8	2.8

(a) 1-in. gage length
(og) broke outside gage length
(k) broke under extensometer knife edge

Table X

75° F TENSILE PROPERTIES FOR Be-38% Al SHEET
(Annealed temper, 0.060-in. thick)
Strain rate to 1% strain: ~ 0.005/min.
Strain rate beyond 1% strain: ~ 0.06/min.

Heat No.	Longitudinal					Transverse				
	Speci- men No.	T.Y.S. (ksi)	T.S. (ksi)	Elong. (%)(a)	R.A. (%)	Speci- men No.	T.Y.S. (ksi)	T.S. (ksi)	Elong. (%)(a)	R.A. (%)
21-30	3B-1	36.9	51.9	9.9o.g.(b)	9.6	3B-37	35.4	50.8	8.0	10.0
	3B-4	35.9	50.2	9.9o.g.	6.7	3B-32	36.3	53.2	10.8	10.8
	3B-7	35.7	51.8	12.7o.g.	8.9	3B-35	33.7	52.0	9.8o.g.	10.9
						3C-1	35.8	51.6	9.6	10.9
						3C-4	35.8	51.9	10.0	9.3
	Avg.	36.2	51.3	10.8	8.4	Avg.	35.4	51.9	9.6	10.4
21-31	2B-23	36.8	50.7(c)	9.1(c)	9.2	2B-27	34.8	49.4	9.2	7.9
	2C-5	33.7	42.3(c)	3.2(c)	3.2	2C-19	34.6	48.0	6.3	6.9
	2C-6	34.9	41.8(c)	3.5(c)	3.5	2C-20	34.4	48.2	6.8	7.4
	2C-10	34.3	48.8	9.0	9.1	2C-21	34.5	47.8	6.0	6.4
	Avg.	34.9	45.9	6.2	6.2	Avg.	34.6	48.4	7.1	7.2
21-34	300A-13	38.4	54.3	7.6	7.0	300A-29	38.4	52.2	7.0	8.5
	300A-14	38.4	53.2	6.6	7.0	300A-30	38.1	52.7	8.2	8.3
	300A-15	39.0	54.5	8.0	8.3	300A-31	38.5	52.5	8.1	7.8
	Avg.	38.6	54.0	7.4	7.4	Avg.	38.3	52.5	7.8	8.2
Avg. for 3 heats		36.3	49.9	7.8	7.0		36.0	50.8	7.9	8.5

(a) 1-in. gage length
(b) o.g. = Broke outside gage length
(c) Defects: deep transverse scratches from severe surface grinding

Table XI

400° F TENSILE PROPERTIES FOR Be-38% Al SHEET

(Annealed temper, 0.060-in. thick)
Strain rate to 1% strain: ~ 0.005/min.
Strain rate beyond 1% strain: ~ 0.08/min.

Heat No.	Specimen No.	T.Y.S. (ksi)	T.S. (ksi)	Elong. (%)[a]	R.A. (%)	Specimen No.	T.Y.S No.	T.S. (ksi)	Elong. (%)[a]	R.A. (%)
21-30	3C-7	30.4	38.9	8.6	12.6	3C-16	31.3	39.5	13.1	18.6
	3C-3	31.0	39.0	9.2	12.8	3C-17	31.1	40.0	11.0	14.9
	3C-9	30.7	38.4	10.3	13.8	3C-18	29.6	39.0	11.8	14.0
		30.7	38.8	9.4	13.1		30.7	39.5	12.0	15.8
21-31	2A-2	29.7	37.8	12.1	18.4	2A-1	29.6	38.2	11.3	14.4
	2A-7	29.0	38.0	12.5	15.4	2A-3	30.1	38.1	11.9	16.7
	2A-8	29.6	37.7	10.9	15.7	2A-5	30.2	38.0	12.2	16.5
		29.4	37.8	11.8	16.5		30.0	38.1	11.8	15.9
21-34	303B-1	32.6	41.0	11.8	11.5	303B-10	31.5	39.8	12.2	8.7
	303B-2	31.8	40.5	13.7	14.0	303B-11	33.8	42.1	11.9	13.4
	303B-3	33.1	39.7	6.1	6.7	303B-12	33.9	42.8	11.6	14.3
		32.5	40.4	10.5	10.7		33.1	41.6	11.9	12.1
Avg. for 3 heats		30.9	39.0	10.6	13.4		31.3	39.7	11.9	14.6

Table XII

800° F TENSILE PROPERTIES FOR Be – 38% Al SHEET
(Annealed Temper, 0.060-in. Thick)
Strain rate to 1% strain: ~ 0.005/min.
Strain rate beyond 1% strain: ~ 0.08/min

Heat No.	Longitudinal					Transverse				
	Specmen No.	T.Y.S. (ksi)	T.S. (ksi)	Elong (%)(a)	R.A. (%)	Specmen No.	T.Y.S. (ksi)	T.S. (ksi)	Elong (%)(a)	R.A. (%)
21-30	3B-2	19.9	23.2	6.2	13.9	3B-34	20.0	22.7	11.2	16.8
	3B-3	19.7	23.2	4.8	10.5	3B-36	20.3	23.5	5.0	12.6
	3B-5	19.5	23.1	5.8	11.8	3B-38	20.1	23.6	6.0	12.0
		19.7	23.2	5.8	12.1		20.1	23.3	7.4	13.8
21-31	2A-9	20.8	24.0	3.2	9.1	2A-4	20.7	23.6	4.5	10.4
	2A-10	20.4	23.9	4.5	9.9	2A-6	20.0	23.8	4.0	9.7
	2A-11	21.1	24.0	3.9	8.1	2A-X2	19.7	22.7	4.8	12.3
		20.8	24.0	3.9	9.0		20.1	23.4	4.4	10.8
21-34	303B-26	22.8	26.4	6.2	11.9	300A-68	22.2	25.7	4.4	8.9
	303B-27	22.4	25.1	4.7	10.9	300A-69	21.5	25.6	4.9	9.4
	300A-67	22.4	25.7	4.8	10.8	300A-70	22.0	25.2	5.1	9.0
		22.5	25.7	5.2	11.2		21.9	25.5	4.8	9.1
Avg. for 3 heats		21.0	24.3	5.0	10.8		20.7	24.1	5.5	11.2

Table XIII

EFFECT OF 400° F AND 800° F EXPOSURE ON THE
75° F TENSILE PROPERTIES OF Be-38% Al EXTRUSIONS
(Annealed; Strain rate: ~0.005/min to 1% strain; ~0.08/min beyond 1% strain)

Heat No.	Exposure Time (hr)	400° F AIR EXPOSURE					800° F AIR EXPOSURE				
		Longitudinal					Longitudinal				
		Specmen No.	T.Y.S. (ksi)	T.S. (ksi)	Elong (%)[b]	R.A. (%)	Specmen No.	T.Y.S. (ksi)	T.S. (ksi)	Elong (%)[b]	R.A. (%)
21-33	0[a]	4A, 5B	44.5[3]	57.0[3]	7.6[3]	7.4[3]	4A	44.5[3]	57.0[3]	7.6[3]	7.4[3]
	10	5A-12	45.8	58.6	8.0	8.8	5A-18	45.6	58.2	7.4	7.0
	10	5A-13	45.5	57.5	7.5	8.4	5A-19	45.6	56.9	6.6	8.7
		Avg.	45.7	58.1	7.8	8.6		45.6	57.6	7.0	7.9
	100	5A-14	45.5	57.2	7.6	8.6	5A-20	45.3	58.0	7.8	8.3
	100	5A-15	44.4	56.1	7.4	8.4	5A-21	44.2	56.7	6.9	7.7
		Avg.	45.0	56.7	7.5	8.5		44.8	57.4	7.4	8.0
	1000	5A-16	45.0	57.2	8.5	8.3	5A-22	42.8	55.3	7.6	9.4
	1000	5A-17	45.8	56.6	6.0og	5.0	5A-23	44.9	58.8	10.1	9.7
		Avg.	45.4	56.9	7.3	6.6		43.9	57.1	8.9	9.6
21-32	0[a]	2A, 8	44.9[3]	58.1[3]	7.3[3]	6.8[3]	2A, 8	44.9[3]	58.1[3]	7.3[3]	6.8[3]
	10	2A-1	44.8	57.8	7.8	7.2	2A-7	45.7	59.5	9.0	8.8
	10	2A-2	44.9	57.0	7.2og	7.4	2A-8	45.9	58.9	8.3	7.5
		Avg.	44.8	57.4	7.5	7.3		45.8	59.2	8.7	8.2
	100	2A-3	44.7	56.9	8.2	8.0	2A-9	45.3	58.8	7.9og	6.8
	100	2A-4	44.3	53.7	4.1og	6.1	2A-13	45.9	59.2	8.0	7.8
		Avg.	44.5	55.3	6.2	7.0		45.6	59.0	8.0	7.3
	1000	2A-5	44.6	56.4	8.3	8.4	2A-14	44.5	57.6	8.3	10.7
	1000	2A-6	44.9	56.6	6.9	7.9	2A-15	44.6	57.5	7.2	7.6
		Avg.	44.8	56.5	7.6	8.2		44.6	57.6	7.8	9.2
21-35	0[a]	307	44.2[3]	54.4[3]	5.1[3]	5.4[3]	307	44.2[3]	54.4[3]	5.1[3]	5.4[3]
	10	307-1	42.8	50.7	4.1	3.8	307-7	44.7	54.4	5.9	4.6
	10	307-2	43.4	51.1	4.8	4.3	307-8	45.0	54.4	4.6	3.7
		Avg.	43.1	50.9	4.4	4.0		44.9	54.4	5.3	4.2
	100	307-3	43.0	51.3	5.3og	4.5	307-9	44.4	53.2	5.2	5.1
	100	307-4	43.4	52.1	5.7og	3.7	307-10	45.5	54.9	5.2	5.9
		Avg.	43.2	51.7	5.5	4.1		45.0	54.0	5.2	5.5
	1000	307-5	45.0	51.8	4.2	3.8	307-11	44.1	52.3	4.9	6.9
	1000	307-6	44.8	52.0	4.8og	3.1	307-12	44.1	53.3	5.1	6.4
		Avg.	44.9	51.9	4.5	3.4		44.1	52.8	5.0	6.6

(a) See tensile data for details on control tests
(b) 1-in. gage length
(c) og = failed outside gage length

Table XV

COMPRESSION YIELD STRENGTH FOR Be-38% Al EXTRUSIONS
(Annealed temper, ground condition, 3/16 in. × 2-1/2 in. bar)
Strain rate: ~ 0.005/min.

Test Temp. (°F)	Heat 21-33				Heat 21-32				Heat 21-35			
	Longitudinal		Transverse		Longitudinal		Transverse		Longitudinal		Transverse	
	Specimen No.	C.Y.S. (ksi)	Specimen No.	C.Y.S. (ksi)	Specimen No.	C.Y.S. (ksi)	Specimen No.	C.Y.S. (ksi)	Specimen No.	C.Y.S. (ksi)	Specimen No.	C.Y.S. (ksi)
75	4A-5	42.8	4A-23	41.3	8-28	38.1	8-37	38.7	309-25	44.0	309-12	43.9
	4A-12	41.4	4A-42	39.9	2A-36	38.0	2A-30	39.8	309-26	45.1	309-13	43.1
	4A-21	41.3	4A-55	42.8	8-48	42.0	8-45	40.2	309-27	42.4	309-14	43.6
	Avg.	41.8		41.3		39.4		39.6		43.8		43.5
400	4A-8	36.2	4A-41	36.9	2A-37	35.0	8-44	35.2	307-21	35.5	307-18	36.0
	4A-9	36.4	4A-57	35.1	2A-41	34.2	2A-45	36.6	307-22	35.7	307-19	35.6
	4A-13	36.1	4A-39	34.7	2A-42	33.5	2A-46	36.7	307-23	(a)	307-20	37.5
	Avg.	36.2		35.6		34.2		36.2		35.6		36.4
800	4A-16	14.3	5B-37	12.5	8-51	14.6	8-34	11.5	307-24	15.2	307-35	11.6
	4A-17	12.6	5A-X	10.4	8-41	15.0	8-43	12.5	307-25	16.3	307-36	11.7
	4A-20	14.2	5B-A	12.8	8-47	15.0	2A-44	12.1	309-20	14.7	307-37	11.8
	Avg.	13.7		11.9		14.9		12.0		15.4		11.7

(a) Extensometer malfunction

Table XIV

EFFECT OF 400° F AND 800° F EXPOSURE ON THE 75° F TENSILE PROPERTIES OF Be-38% Al SHEET (Annealed; strain rate: ~0.005/min to 1% strain; ~0.08/min beyond 1% strain)

Heat No.	Exposure Time (hr)	400° F AIR EXPOSURE										800° F AIR EXPOSURE									
		Longitudinal					Transverse					Longitudinal					Transverse				
		Specimen No.	T.Y.S. (ksi)	T.S. (ksi)	Elong. (%)(b)	R.A. (%)	Specimen No.	T.Y.S. (ksi)	T.S. (ksi)	Elong. (%)(b)	R.A. (%)	Specimen No.	T.Y.S. (ksi)	T.S. (ksi)	Elong. (%)(b)	R.A. (%)	Specimen No.	T.Y.S. (ksi)	T.S. (ksi)	Elong. (%)(b)	R.A. (%)
21-30	0(a)	3B	36.2^{3} (c)	51.3^{3}	10.8^{3}	8.4^{3}	3B	35.4^{5}	51.9^{5}	9.6^{5}	10.1^{5}	3B	36.2^{3}	51.3^{3}	10.8^{3}	8.4^{3}	3B	35.4^{5}	51.9^{5}	9.6^{5}	10.1^{5}
	10	3D-1	34.7	48.8	9.5	12.3	3D-18	36.5	52.5	10.1	12.4	3D-2	34.6	50.0	7.8	9.4	3D-19	34.6	50.7	10.8	14.9
	10	3D-4	36.4	50.5	8.9	6.9	3D-23	36.1	52.0	9.7	9.6	3D-3	34.7	51.0	10.0	10.8	3D-20	36.6	46.7	11.0	10.8
		Avg.	35.6	49.7	8.2	9.6		36.3	52.2	9.9	11.0		34.6	50.5	8.9	10.1		35.6	48.7	10.9	12.8
	100	3D-5	35.5	50.0	9.3	10.8	3D-21	36.5	51.8	10.2	10.5	3D-9	34.9	51.4	11.2	12.7	3D-17	35.4	50.0	6.6	7.3
	100	3D-6	34.2	50.0	10.2	13.4	3D-22	36.8	51.6	12.8	13.2	3D-10	35.3	51.2	9.0 og(d)	7.8	3D-18	35.0	51.3	8.8	9.1
		Avg.	34.9	50.0	9.8	12.1		36.7	51.7	11.5	11.8		35.1	51.3	10.1	10.2		35.2	50.6	7.6	8.2
	1000	3D-7	34.6	49.7	9.6	10.0	3D-41	36.4	51.4	10.2	7.1	3D-11A	35.0	51.2	8.4	8.7	3D-24	35.7	51.0	8.2	9.0
	1000	3D-8	35.5	48.3	7.7	9.9	3D-42	36.1	49.5	7.9	10.0	3D-11B	34.6	50.0	8.9	10.4	3D-25	36.1	52.9	13.2	14.4
		Avg.	35.0	49.0	8.7	10.0		38.2	50.5	9.1	8.6		34.8	50.6	8.6	9.6		35.4	52.0	10.7	11.7
21-31	0(a)	2C	34.3^{3}	44.3^{3}	5.2^{3}	5.3^{3}	2C	34.5^{3}	48.0^{3}	6.4^{3}	6.9^{3}	2C	34.3^{3}	44.3^{3}	5.2^{3}	5.3^{3}	2C	34.5^{3}	48.0^{3}	6.4^{3}	6.9^{3}
	0	2B	36.8	50.7	9.1	9.2	2B	34.8	49.4	9.2	7.9	2B	36.8	50.7	9.1	9.2	2B	34.8	49.4	9.2	7.9
	10	2B-5	38.9	50.0	7.3	10.5	2B-17	38.1	50.0	6.7	8.4	2B-1	39.3	51.0	6.9	11.5	2B-13	39.7	52.6	8.5	8.9
	10	2B-6	39.3	50.6	7.6	9.2	2B-18	38.8	50.1	7.8	10.1	2B-2	39.1	50.0	5.7	7.9	2B-14	39.4	52.3	8.6	10.6
		Avg.	39.1	50.3	7.5	9.9		38.4	50.0	7.2	9.2		39.2	50.5	6.3	9.7		39.6	52.5	8.6	9.8
	100	2B-7	38.8	47.0	4.5	6.0	2B-19	37.3	47.2	5.8	7.8	2B-3	39.8	51.4	7.9	9.4	2B-15	38.5	51.3	7.0	7.0
	100	2B-8	38.1	47.8	5.9	8.3	2B-20	38.0	47.3	5.9	5.9	2B-4	39.2	50.6	7.0	10.8	2B-16	38.0	52.1	9.1	11.0
		Avg.	38.5	47.4	5.2	6.6		37.7	47.3	5.9	8.8		39.4	51.0	7.4	10.1		38.2	51.7	8.0	9.0
	1000	2B-25	38.0	51.4	9.6	10.4	2B-11	39.5	48.5	5.5	8.7	2B-21	38.1	50.4	7.4	12.2	2B-9	38.0	53.1	9.7	10.1
	1000	2B-24	38.2	(e)	(e)	(e)	2B-12	38.2	48.7	5.9	8.2	2B-22	38.6	51.2	7.9	9.2	2B-10	39.0	52.2	9.0	9.8
		Avg.						38.8	48.6	5.7	8.4		38.4	50.8	7.6	10.7		38.5	52.6	9.4	10.0
21-34	0(a)	300A	38.6^{3}	54.0^{3}	7.4^{3}	7.4^{3}	300A	38.3^{3}	52.5^{3}	7.8^{3}	8.2^{3}	300A	38.6^{3}	54.0^{3}	7.4^{3}	7.4^{3}	300A	38.3^{3}	52.5^{3}	7.8^{3}	8.2^{3}
	10	300A-1	40.4	53.4	8.0	7.8	300A-21	39.2	52.3	7.0	6.3	300A-2	39.3	53.7	7.4	8.2	300A-17	38.5	53.4	8.0	8.1
	10	300A-6	39.6	53.2	7.9	8.1	300A-22	39.0	51.4	5.7	5.8	300A-5	39.7	54.8	9.2	8.3	300A-18	38.8	51.9	6.9	6.2
		Avg.	40.0	53.3	8.0	8.0		39.1	51.9	6.4	5.9		39.5	54.2	8.3	8.2		38.6	52.6	7.4	7.2
	100	300A-7	39.2	49.7	5.1	5.4	300A-23	38.9	51.2	6.1	7.5	300A-3	40.0	53.6	6.6	6.9	300A-19	39.7	53.5	7.9	8.2
	100	300A-8	39.0	52.7	8.1	8.7	300A-24	38.2	51.0	6.0	6.1	300A-4	39.6	55.3	9.7	8.0	300A-20	39.3	46.4	3.5	4.5
		Avg.	39.1	51.2	6.6	7.0		38.6	51.1	6.0	6.8		39.8	54.4	8.2	7.4		39.5	50.0	5.7	6.4
	1000	300A-11	39.4	52.2	7.2	5.8	300A-27	38.3	52.8	8.2	9.3	300A-9	39.7	53.4	7.8	7.3	300A-25	38.7	52.0	7.0	5.9
	1000	300A-12	39.6	53.2	8.2	7.1	300A-28	39.1	51.8	7.5	8.1	300A-10	39.7	53.7	7.9	8.0	300A-26	38.7	50.7	5.6	6.7
		Avg.	39.5	52.7	7.7	6.4		38.7	52.3	7.9	8.7		39.7	53.8	7.8	7.6		38.7	51.4	6.3	6.3

(a) See tensile data tables for details
(b) 1-in. gage length
(c) Exponents = number of tests
(d) og = failed outside gage length
(e) Defect – dross inclusion

Table XVI

COMPRESSION YIELD STRENGTH FOR Be-38% Al SHEET
(Annealed temper, 0.060-in. sheet)
Strain Rate: ~ .005/min

Test Temp., °F	Heat 21-30				Heat 21-31				Heat 21-34			
	Longitudinal		Transverse		Longitudinal		Transverse		Longitudinal		Transverse	
	Specimen No.	C.Y.S. (ksi)	Specimen No.	C.Y.S. (ksi)	Specimen No.	C.Y.S. (ksi)	Specimen No.	C.Y.S. (ksi)	Specimen No.	C.Y.S. (ksi)	Specimen No.	C.Y.S. (ksi)
75	3B-42	33.8	3B-18	33.8	2C-27	31.9	2C-31	33.2	300A-48	36.6	300A-53	35.0
75	3C-38	35.1	3C-33	32.7	2C-29	32.1	2C-32	32.8	300A-49	36.5	300A-54	37.7
75	3D-33	33.2	3D-38	33.8	2C-14	32.2	2C-33	32.8	300A-59	36.7	300A-55	37.2
	Avg.	34.0		33.4		32.1		32.9		36.6		36.6
400	3B-43	27.1	3B-20	27.5	2C-15	25.7	2A-12	27.2	303B-15	30.9	303B-21	30.4
400	3C-39	28.1	3C-35	26.9	2C-17	25.4	2A-13	27.3	303B-17	29.3	303B-39	31.3
									303B-16	29.3		
	Avg.	27.6		27.2		25.6		27.2		29.8		30.8
800	3D-34	14.4	3B-19	14.5	2A-14	13.0	2A-40	13.7	303B-A	15.0	303B-23	15.1
800	3D-35	14.2	3D-40	14.5	2A-15	13.4	2A-41	13.4	303B-X	14.1	303B-22	15.1
800							2A-42	13.4				
	Avg.	14.3		14.5		13.2		13.5		14.6		15.1

Table XVII

COMPRESSION SECANT YIELD STRENGTH FOR Be-38% Al EXTRUSIONS

(Annealed temper, ground condition, 3/16 in. × 2-1/2 in. bar)
Strain rate: ~ .005/min

Test Temp. (°F)	Heat 21-33				Heat 21-32				Heat 21-35			
	Longitudinal		Transverse		Longitudinal		Transverse		Longitudinal		Transverse	
	Specimen No.	0.7 S.Y.S. (ksi)	Specimen No.	0.7 S.Y.S. (ksi)	Specimen No.	0.7 S.Y.S. (ksi)	Specimen No.	0.7 S.Y.S. (ksi)	Specimen No.	0.7 S.Y.S. (ksi)	Specimen No.	0.7 S.Y.S. (ksi)
75	4A-5	34.6	4A-23	31.3	8-28	32.2	8-37	22.4	309-25	36.9	309-12	35.3
75	4A-12	32.8	4A-42	32.9	2A-36	31.6	2A-30	24.2	309-26	36.6	309-13	28.3
75	4A-21	32.2	4A-55	28.2	8-48	37.3	8-45	25.1	309-27	36.9	309-14	32.2
	Avg.	33.2		30.8		33.7		23.9		36.8		31.9
400	4A-8	34.8	4A-41	36.2	2A-37	30.0	8-44	30.9	309-21	32.9	307-18	32.2
400	4A-9	34.7	4A-57	32.3	2A-41	28.5	2A-45	32.9	307-22	34.7	307-19	33.0
400	4A-13	34.3	4A-39	30.1	2A-42	31.0	2A-46	35.3	307-23	--	307-20	35.5
	Avg.	34.6		32.9		29.8		33.0		33.8		32.9
800	4A-16	12.5	5B-37	10.7	8-51	12.6	8-34	10.4	307-24	12.8	307-35	9.4
800	4A-17	11.3	5A-X	9.5	8-41	12.9	8-43	10.6	307-25	12.5	307-36	10.0
800	4A-20	10.8	5B-A	10.9	8-47	12.9	2A-44	11.2	309-20	12.5	307-37	10.7
	Avg.	11.5		10.4		12.8		10.7		12.6		10.0

Table XVIII

COMPRESSION SECANT YIELD STRENGTH FOR Be-38% Al SHEET
(Annealed temper, 0.060-in. sheet)

Test Temp. (°F)	Heat 21-30				Heat 21-31				Heat 21-34			
	Longitudinal		Transverse		Longitudinal		Transverse		Longitudinal		Transverse	
	Speci-men No.	0.7 Sec Y.S. (ksi)	Speci-men No.	0.7 Sec Y.S. (ksi)	Speci-men No.	0.7 Sec Y.S. (ksi)	Speci-men No.	0.7 Sec Y.S. (ksi)	Speci-men No.	0.7 Sec Y.S. (ksi)	Speci-men No.	0.7 Sec Y.S. (ksi)
75	3B-42	20.5	3B-18	21.8	2C-27	21.7	2C-31	22.7	300A-48	23.2	300A-53	27.5
75	3C-38	24.5	3C-33	25.3	2C-29	21.8	2C-32	22.4	300A-49	25.8	300A-51	29.5
75	3D-33	23.6	3D-38	26.4	2C-14	23.1	2C-33	22.2	300A-59	28.0	300A-55	28.1
	Avg.	22.9		24.5		22.2		22.4		25.7		28.4
400	3B-43	23.7	3B-20	21.3	2C-15	23.3	2A-12	23.3	303B-15	26.2	303B-21	26.6
400	3C-39	24.5	3C-35	23.6	2C-17	20.3	2A-13	24.7	303B-17	26.0	303B-39	27.7
400									303B-16	25.0		
	Avg.	24.1		22.4		21.8		23.6		25.7		26.8
800	3D-34	12.1	3B-19	12.5	2A-14	10.7	2A-40	11.1	303B-A	12.9	303B-23	13.2
800	3D-35	10.7	3D-40	12.8	2A-15	11.3	2A-41	11.0	303B-X	13.5	303B-22	13.1
800							2A-42	11.5				
	Avg.	11.4		12.6		11.0		11.2		13.2		13.2

Table XIX

SHEAR STRENGTH OF Be-38% Al EXTRUSIONS
(Annealed temper, 3/16 in. × 2-1/2 in. bar, 0.125 in. diam. test specimen, pin double shear method, 0.1 in./min. cross-head rate)

Test Temp. (°F)	Heat 21–33 (5B) Shear Strength (ksi)(a)				Heat 21–32 Shear Strength (ksi)				Heat 21–35 Shear Strength (ksi)			
	yz-z	yz-y	xz-z	xz-x	yz-z	yz-y	xz-z	xz-x	yz-z	yz-y	xz-z	xz-x
75	34.6	39.8	24.7	31.0	32.7	39.8	23.4	28.4	39.3	43.5	26.5	26.9
75	35.8	39.5	28.3	29.5	35.1	37.7	23.9	28.9	39.5	43.9	28.5	30.8
75	35.9	39.2	28.8	28.2	35.8	40.1	25.6	28.9	38.9	43.5	29.4	29.4
					39.5							
Avg.	35.4	39.5	27.3	29.6	35.8	39.2	24.3	28.8	39.2	43.6	28.1	29.0
400	26.1	29.0	21.8	22.8	25.8	28.2	22.4	23.6	27.4	29.6	24.4	25.0
400	26.0	29.1	21.8	23.2	26.3	28.2	22.1	23.5	26.8	29.8	23.6	25.4
400	—	29.2	—	—	26.2	—	—	—	—	—	—	—
Avg.	26.0	29.1	21.8	23.0	26.1	28.2	22.2	23.6	27.1	29.7	24.0	25.2
600(e)	19.4	21.5	16.2	17.4	19.3	21.0	18.5	19.0	20.4	21.7	19.5	20.6
800	12.6	13.8	11.7	12.3	12.4	13.6	12.0	12.5	13.4	14.7	12.2	13.3
800	12.8	14.0	11.8	12.7	12.1	13.8	12.0	12.9	13.4	14.8	11.8	13.4
Avg.	12.7	13.9	11.8	12.5	12.2	13.7	12.0	12.7	13.4	14.8	12.0	13.4

(a) Shear plane and direction referred to coordinate system.
(b) yz = transverse plane
xz = longitudinal plane
x = longitudinal direction
y = long transverse direction
z = short transverse direction
(e) 600° F values obtained by interpolation

Table XX

SHEAR STRENGTH OF Be-38% Al SHEET

(Annealed temper, 0.060-in. thick, 0.01 in./min. cross-head rate, sheet-single-shear method)

Test Temp. (°F)	Heat 21-30 Shear Strength (ksi)				Heat 21-31 Shear Strength (ksi)				Heat 21-34 Shear Strength (ksi)			
	Specimen No.	xz-x[a]	Specimen No.	yz-y	Specimen No.	xz-x	Specimen No.	yz-y	Specimen No.	xz-x	Specimen No.	yz-y
75	3C-28	24.4	3D-27	27.7	2A-31	26.7	2A-23	26.9	300A-65	27.8	300A-12	28.0
75	3B-46	27.3	3C-13	27.7	2B-33	27.4	2B-36	24.5	303B-5	28.2	303B-28	28.2
	Avg.	25.8		27.7		27.0		25.7		28.0		28.1
400	3D-12	21.5	3D-26	21.4	2A-36	20.4	2A-24	21.0	303B-6	23.1	303B-29	22.3
400	3D-13	21.3	3D-28	21.1	2A-37	20.8	2A-25	21.0	303B-7	22.4	303B-30	22.5
	Avg.	21.4		21.2		20.6		21.0		22.8		22.4
600 (interpolation)		17.2[b]		15.5[b]		15.5[b]		16.5[b]		18.1[b]		17.6[b]
800	3C-26	10.5	3C-11	10.2	2A-38	10.6	2B-30	11.1	303B-8	11.3	303B-31	10.9
800	3C-27	10.3	3C-12	10.0	2A-39	10.2	2B-35	10.3	303B-9	11.3	303B-32	12.1
	Avg.	10.4		10.1		10.4		10.7		11.3		11.5

(a) Shear plane and direction:
xz = longitudinal plane   x = longitudinal direction
yz = transverse plane   y = long transverse direction

(b) Value obtained by interpolation

Table XXI

BEARING STRENGTH PROPERTIES FOR Be-38% Al EXTRUSIONS
(Annealed temper, 3/16 in. × 2-1/2 in. bar, e/D = 2[(a)],
3/16-in. diam. pin, 0.1 in./min cross head speed)

Test Temp. (°F)	Heat 21-33				Heat 21-32				Heat 21-35			
	Longitudinal		Transverse		Longitudinal		Transverse		Longitudinal		Transverse	
	F_{bry} (ksi)	F_{bru} (ksi)	F_{bry} (ksi)	F_{bru} (ksi)	F_{bry} (ksi)	F_{bru} (ksi)	F_{bry} (ksi)	F_{bru} (ksi)	F_{bry} (ksi)	F_{bru} (ksi)	F_{bry} (ksi)	F_{bru} (ksi)
75	81.5	89.5	76.0	87.5	82.9	95.0	74.0	90.5	80.6	92.5	98.0	110.9
75	78.8	83.7	71.4	86.8	79.4	87.9	77.8	93.8	80.3	94.6	80.9	98.0
75	—	95.6	75.0	87.0	75.5	90.6	75.6	88.2	74.7	96.3	80.3	90.3
											82.5	96.3
Avg.	80.1^{2}	89.6^{3}	74.0	87.1	79.3^{2}	91.2^{3}	75.8^{3}	90.8^{3}	78.5^{3}	94.5^{3}	85.4^{4}	98.9^{4}
400	67.4	73.9	61.6	72.7	64.1	71.1	59.8	71.0	69.5	77.1	69.6	80.1
400	62.4	65.9	56.1	67.3	63.8	68.8	64.0	74.0	67.7	76.1	68.8	80.0
Avg.	64.9	69.9	58.8	70.0	64.0	70.0	61.9	72.5	68.6	76.6	69.2	80.0
800	—(b)	37.0	28.8	30.8	33.0	35.5	32.2	34.2	—(b)	38.4	31.2	35.2
800	—(b)	36.1	28.4	29.6	31.4	33.6	28.8	30.9	—(b)	37.1	32.3	33.0
800	30.7	37.0							34.0	36.5		33.4
800	31.6	34.9	—	—	—	—	—	—	33.1	35.7	—	35.2
Avg.	31.2	36.2	28.6	30.2	32.2	34.6	30.5	32.6	33.6	36.9	31.8	34.2

(a) e/D = edge distance/pin diam.
(b) Unsatisfactory load-deformation graph, test rerun

Table XXII

BEARING STRENGTH PROPERTIES FOR Be-38% Al SHEET

(Annealed temper, 0.060-in. sheet, e/D = 2[a], 0.1 in./min cross-head speed)

Test Temp. °F	Pin. Diam. (in.)	Heat 21 – 30				Heat 21 – 31				Heat 21 – 34			
		Longitudinal		Transverse		Longitudinal		Transverse		Longitudinal		Transverse	
		F_{bry} (ksi)	F_{bru} (ksi)	F_{bry} (ksi)	F_{bru} (ksi)	F_{bry} (ksi)	F_{bru} (ksi)	F_{bry} (ksi)	F_{bru} (ksi)	F_{bry} (ksi)	F_{bru} (ksi)	F_{bry} (ksi)	F_{bru} (ksi)
75	0.250	67.0	–(b)	66.1	102.5	67.2	96.8	67.1	90.7	71.9	106.6	73.0	90.4
75	0.1875	60.4	96.8	65.2	100.1	62.6	99.3	66.4	97.6	73.3	104.2	72.7	103.0
75	0.1875	63.5	92.8	65.2	95.4	62.8	93.5	69.3	95.8	73.2	108.7	68.5	94.5
75	0.1875			67.5	89.0	65.2	87.9	70.1	92.2	72.0	89.8	80.7	93.6
Avg.		62.0	94.8	66.0	94.8	63.5	93.6	68.6	95.2	72.8	100.9	74.0	97.0
400	0.1875	55.0	65.8	52.8	63.2	52.9	65.2	54.3	66.5	59.6	73.5	59.1	72.1
400	0.1875	53.2	64.8	52.8	64.1	53.5	65.0	53.7	63.2	58.8	73.1	56.8	72.3
Avg.		54.1	65.3	52.8	63.6	53.2	65.1	54.0	64.8	59.2	73.3	58.0	72.2
800	0.1875	27.1	35.1	29.8	32.3	31.0	31.7	29.3	30.1	33.8	35.5	33.1	34.2
800	0.1875	27.9	29.9	27.8	29.4	–(c)	37.5	29.6	31.5	30.7	41.0	31.8	33.6
800	0.1875					28.0	31.8						
Avg.		27.5	32.5	28.8	30.8	29.5	33.7	29.4	30.8	32.2	38.2	32.4	33.9

(a) e/D = edge distance/pin diameter
(b) Broke at wrong end
(c) Unsatisfactory load – deformation graph, test rerun

Table XXIII

BEND DATA FOR Be-38% Al EXTRUSIONS[a]
(Annealed temper, etched condition, 3/16-in. × 2-1/2-in. bar)

Test Temp. (°F)	Heat 21-33				Heat 21-32				Heat 21-35			
	Longitudinal (b)		Transverse		Longitudinal		Transverse		Longitudinal		Transverse	
	Specimen No.	Bend Angle (deg.)	Specimen No.	Bend Angle (deg.)	Specimen No.	Bend Angle (deg.)	Specimen No.	Bend Angle (deg.)	Specimen No.	Bend Angle (deg.)	Specimen No.	Bend Angle (deg.)
-320	5-47A	29.5	5-38A	17	2A-33A	27.5	2A-18A	15.5	309-34A	33	309-38A	15
-320	5-47B	30	5-38B	13	2A-33B	35.	2A-18B	9	309-34B	29	309-38B	13.5
	Avg.	29.7		15		31.2		12.2		31		14.2
75	5-46A	37	5-40A	9	8-26A	37.5	8-27A	9	309-42A	37	309-40A	8
75	5-46B	35	5-40B	9	8-26B	47.	8-27B	8	309-42B	33	309-40B	9
	Avg.	36		9		42.2		8.5		35		8.5
600	5-43A	22.5	5-42A	6.5	2A-21A	19	2A-20A	6	309-33A	27	309-39A	8
600	5-43B	22	5-42B	7	2A-21B	20	2A-20B	7	309-33B	27	309-39B	7
	Avg.	22.2		6.7		19.5		6.5		27		7.5

(a) Three point bend method, 1.5-in. span, 0.25-in. radius mandrel, 0.1-in./min. cross-head rate, etched to 0.054 in. thickness. Specimens: 0.054 in. × 1 in. × 2 in.
(b) Longitudinal and transverse refer to 2-in. specimen direction. Bend direction is 90° to the specimen direction.

Table XXIV

BEND DATA FOR Be-38% Al SHEET[a]
(Annealed temper, etched condition, 0.054-in.-thick)

Test Temp. (°F)	Heat 21-30 Longitudinal (b) Specimen No.	Heat 21-30 Longitudinal (b) Bend Angle (deg.)	Heat 21-30 Transverse Specimen No.	Heat 21-30 Transverse Bend Angle (deg.)	Heat 21-31 Longitudinal Specimen No.	Heat 21-31 Longitudinal Bend Angle (deg.)	Heat 21-31 Transverse Specimen No.	Heat 21-31 Transverse Bend Angle (deg.)	Heat 21-34 Longitudinal Specimen No.	Heat 21-34 Longitudinal Bend Angle (deg.)	Heat 21-34 Transverse Specimen No.	Heat 21-34 Transverse Bend Angle (deg.)
-320	3B-23	33	3B-22	33.5	2A-21	29.5	2A-34	30	303B-35	22	303B-33	32
-320	3B-24	32	3B-45	29	2A-22	29	2A-36	34.5	303B-36	22	303B-34	34
	Avg.	32.5		31.2		29.2		32.2		22		33
75	3C-36	58	3C-31	47	2B-31	43	2B-38	37	300A-44	38	300A-66	28[c]
75	3C-37	38	3C-32	45.5	2B-32	47	2B-39	37	300A-45	38	300A-61	40
	Avg.	48		46.2		45		37		38		34
325					2C-25	48						
					2C-26	42.5						
					Avg.	45.2						
600	3D-31	26	3D-36	35	2A-19	21	2A-33	23	300A-46	23.5	300A-40	22
600	3D-32	30.5	3D-37	40	2A-20	24	2A-35	24	300A-47	25	300A-41	25
	Avg.	28.2		37.5		22.5		23.5		24.2		23.5

(a) Three point bend method, 1.5-in. span, 0.25-in. radius mandrel, 0.1-in./min. cross-head rate, etched to 0.054 in. thickness. Specimens: 0.054 in. × 1 in. × 2 in.

(b) Longitudinal and transverse refer to 2-in. specimen direction. Bend direction is 90° to the specimen direction.

(c) Poor surface

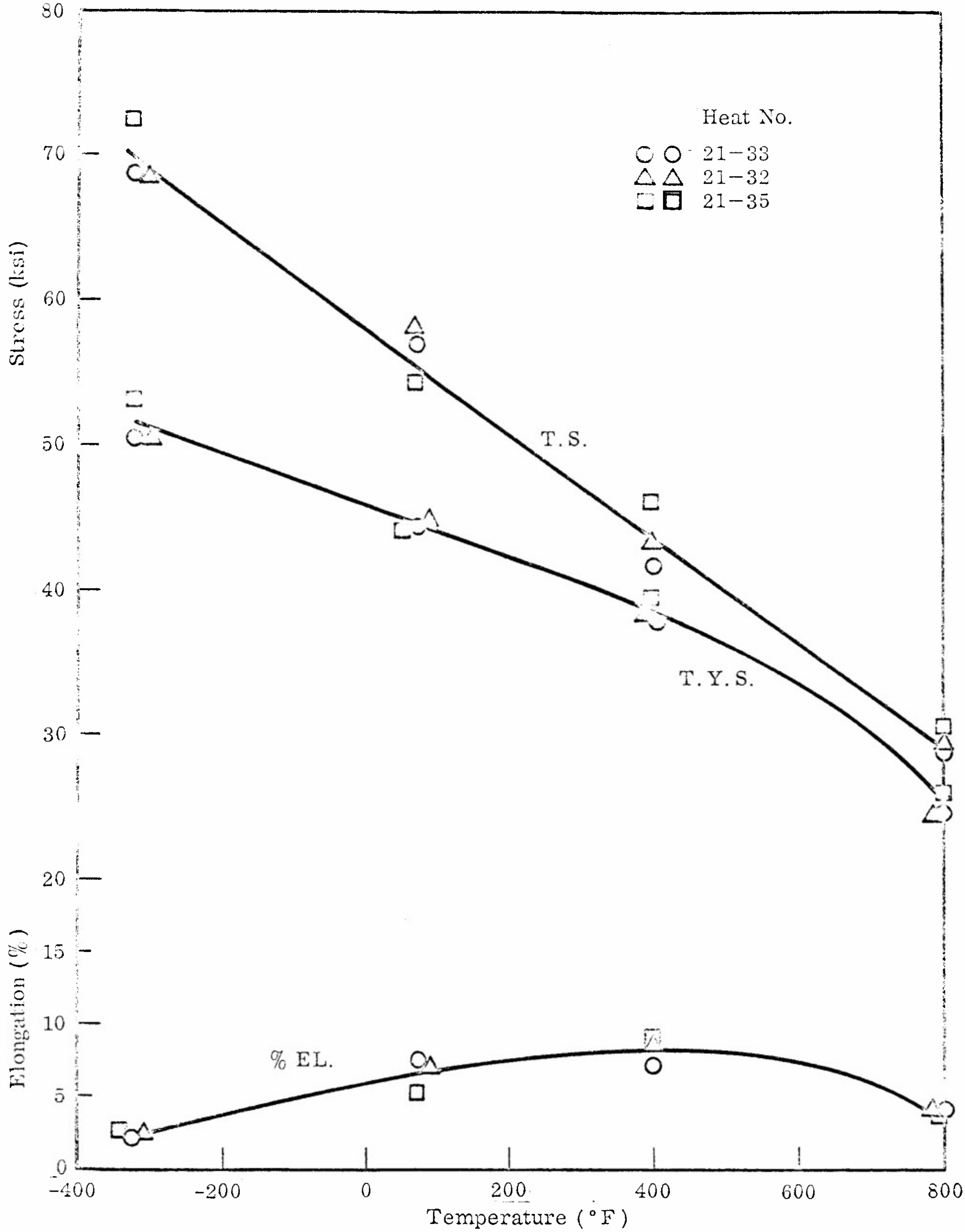


Fig. 2 Longitudinal Tensile Properties of Annealed Be-38% Al Alloy Extrusion as a Function of Temperature (Strain rate: .005/min to T. Y. S., .08/min to T. S.)

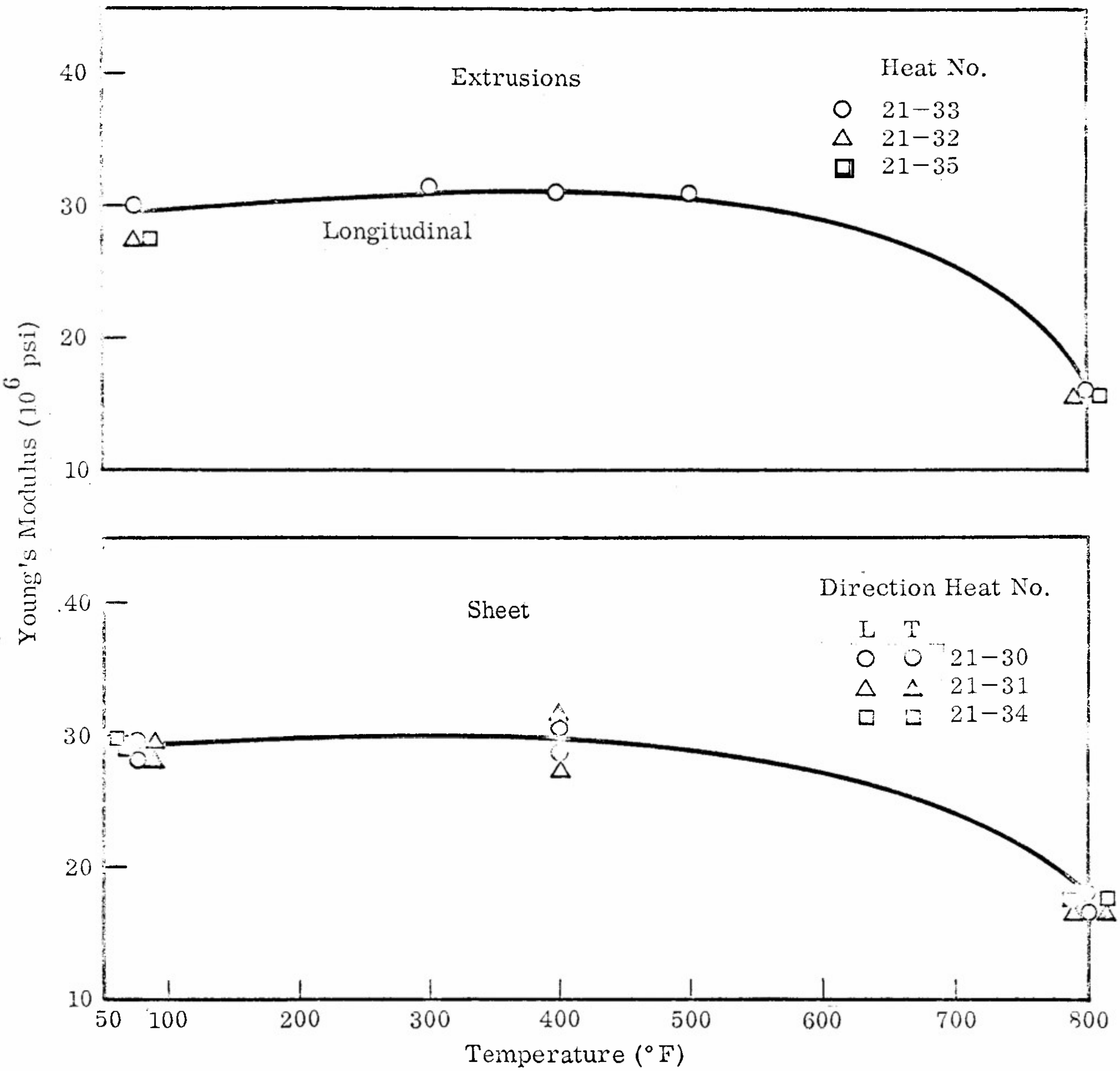


Fig. 1 Young's Modulus of Annealed Be-38% Al Sheet and Extrusion as a Function of Temperature

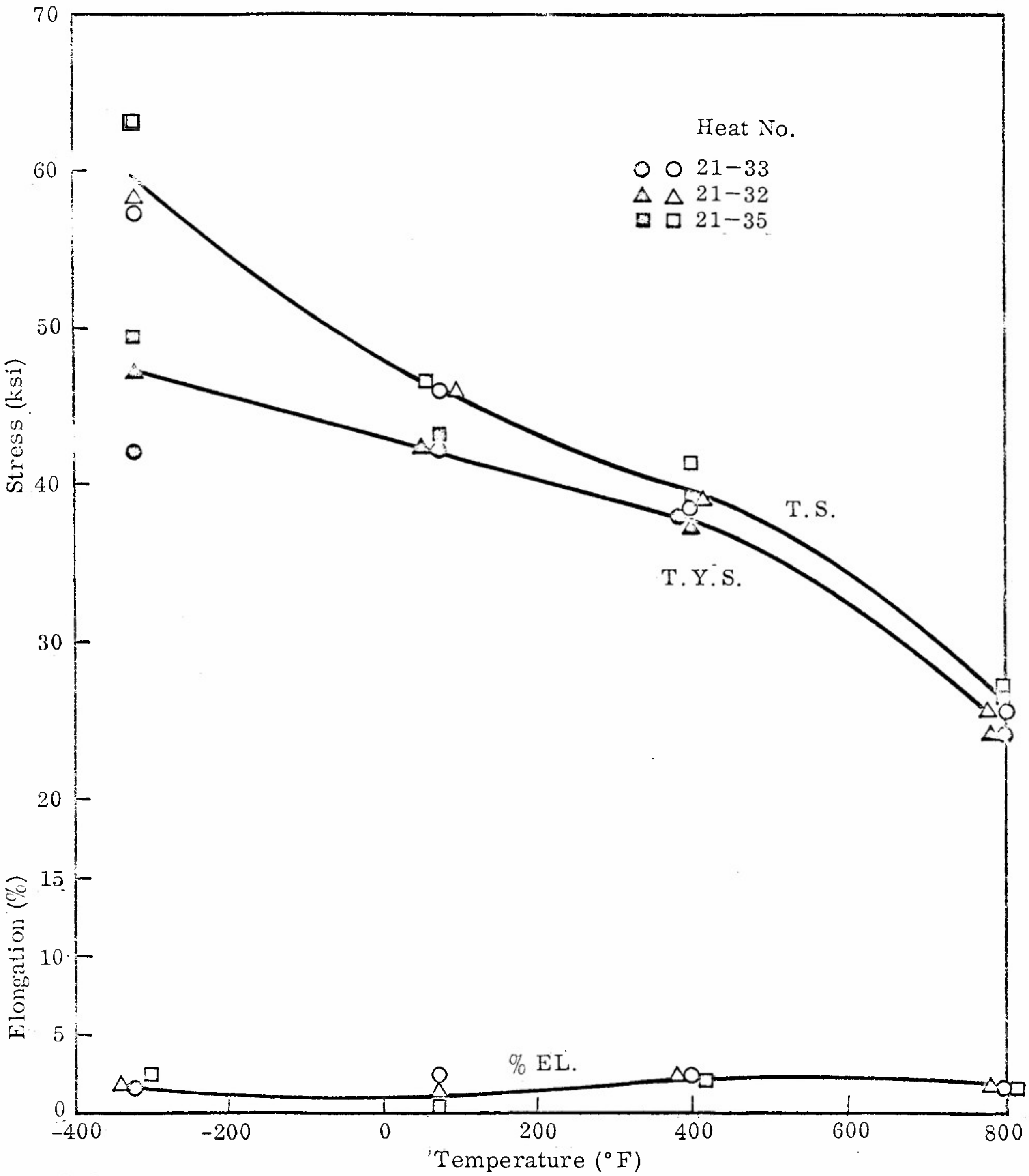


Fig. 3 Transverse Tensile Properties of Annealed Be-38% Al Alloy Extrusion as a Function of Temperature (Strain rate: .005/min to T.Y.S., .08/min to T.S.)

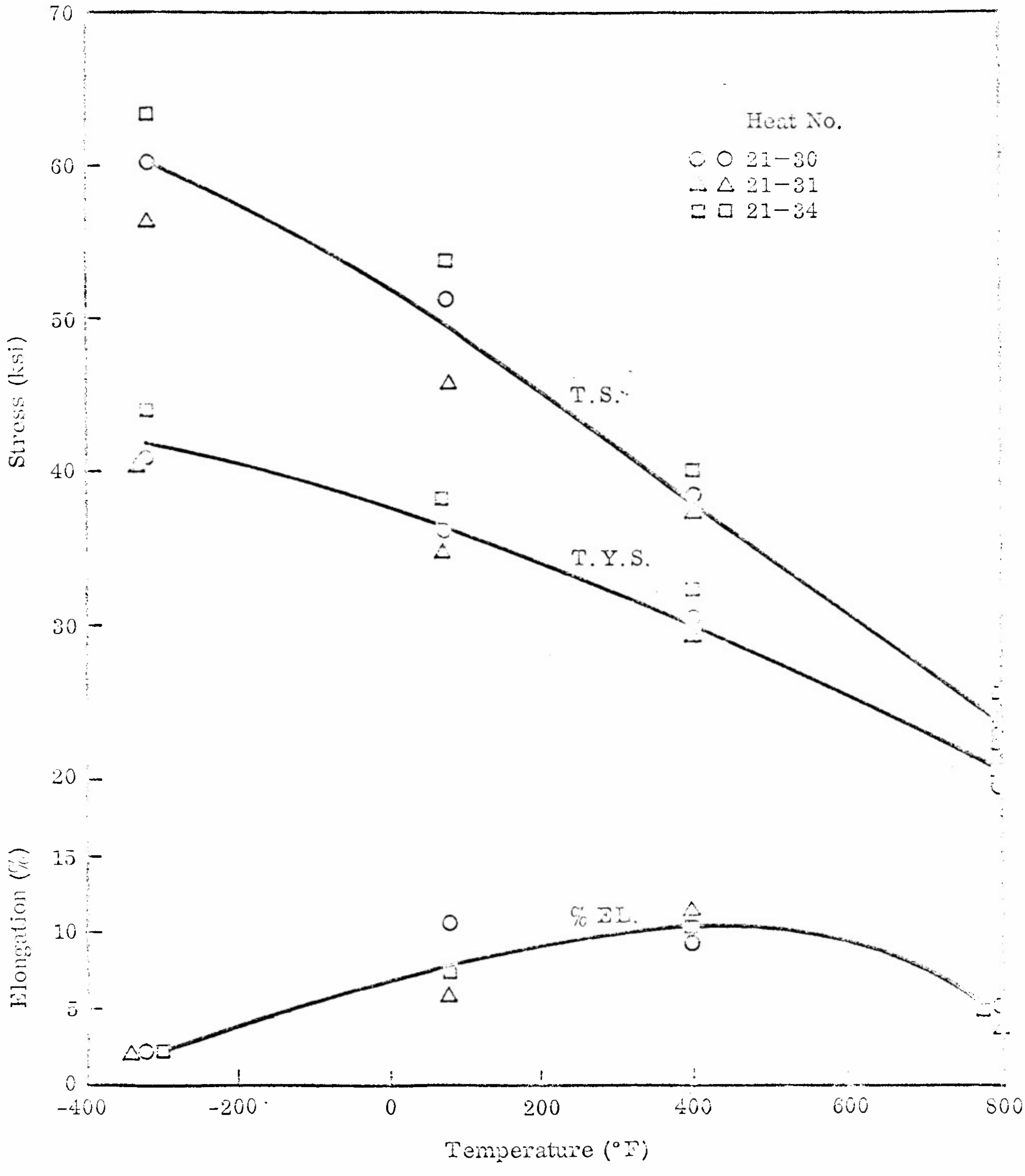


Fig. 4 Longitudinal Tensile Properties of Annealed .060-in.-thick Be-38% Al Alloy Sheet as a Function of Temperature (Strain rate: .005/min to T.Y.S., .08/min to T.S.)

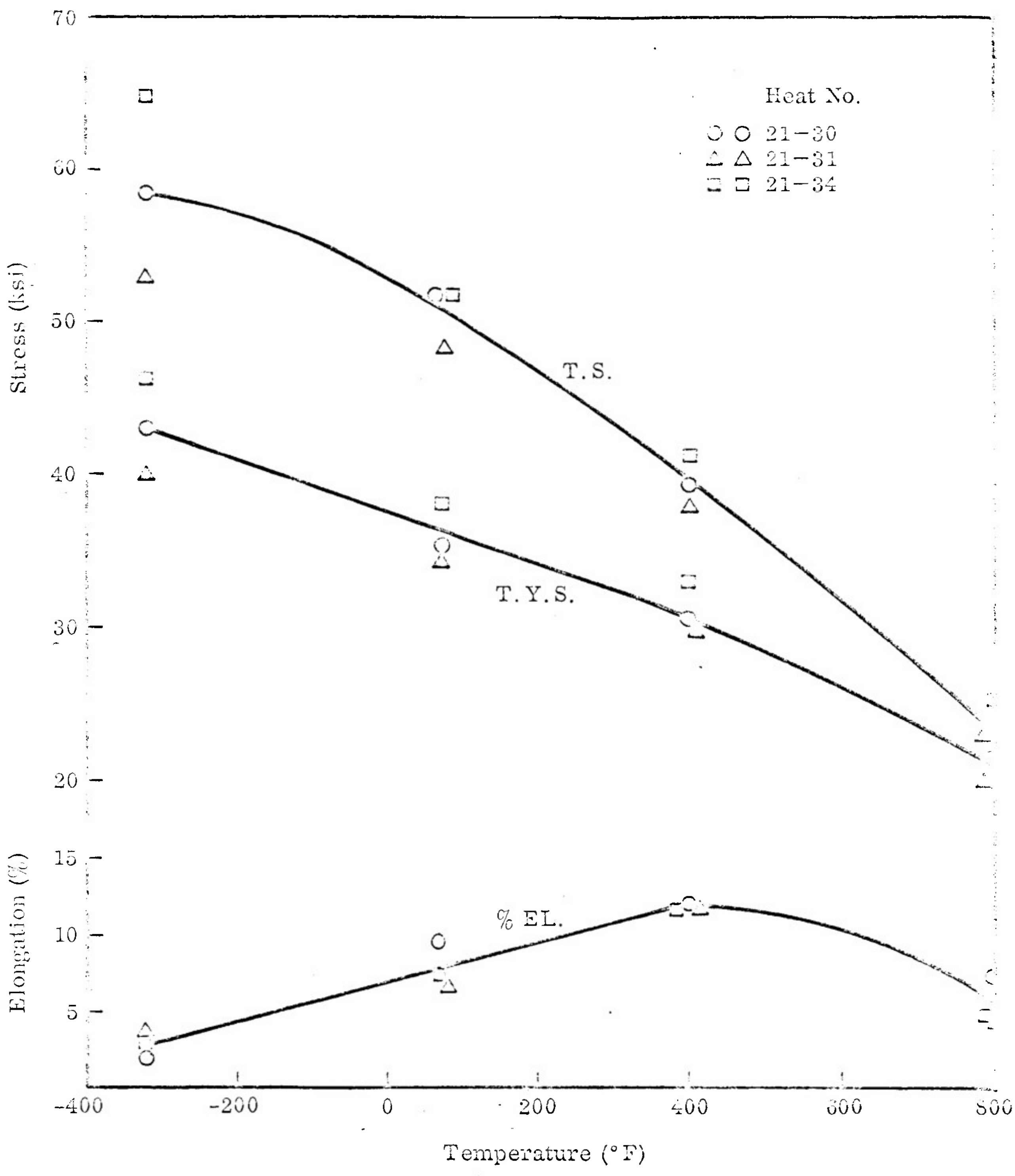


Fig. 5 Transverse Tensile Properties of Annealed 0.060-in.-thick Be-38% Al Alloy Sheet as a Function of Temperature (Strain rate: .005/min to T.Y.S., .08/min to T.S.)

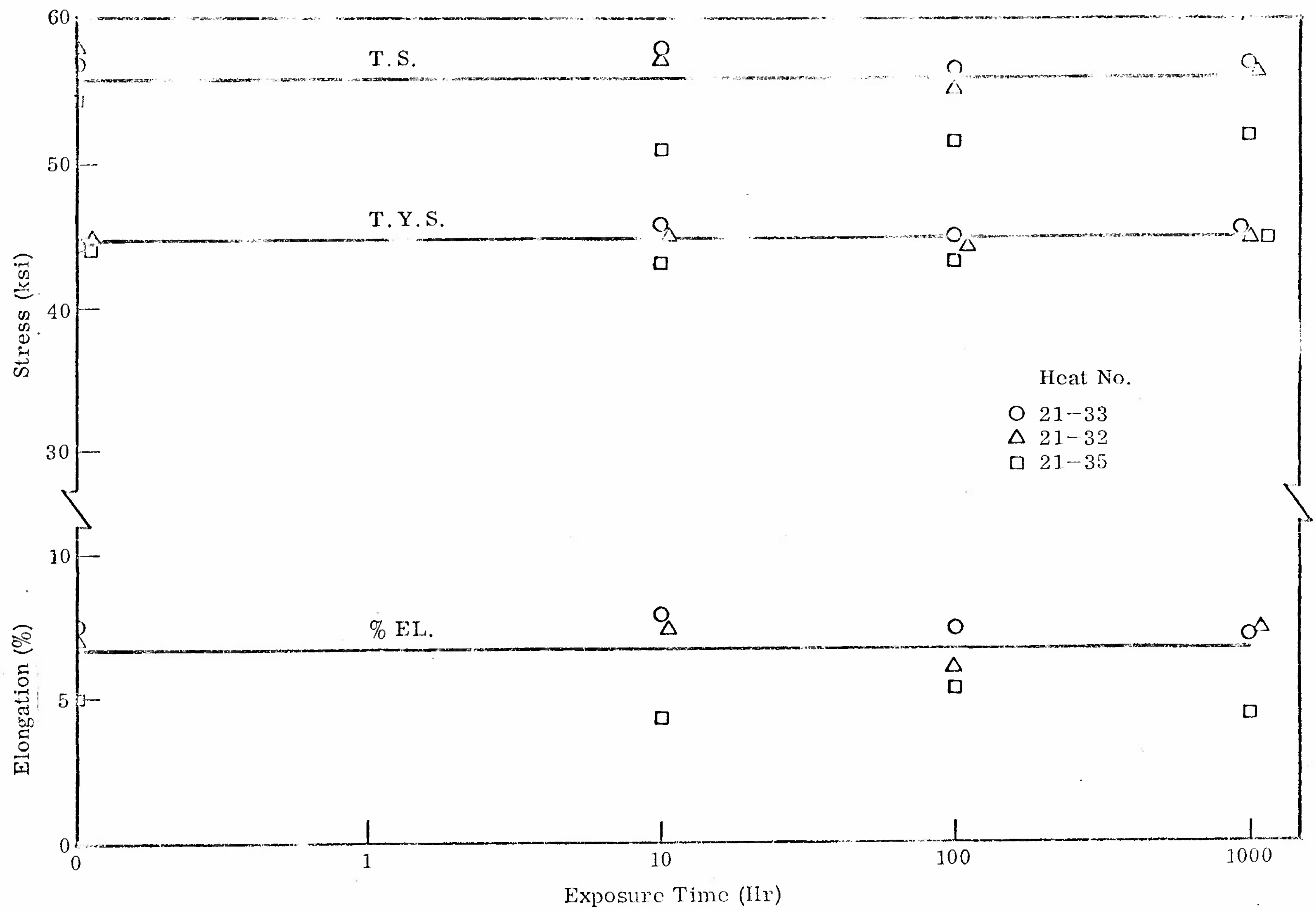


Fig. 6 Longitudinal 75° F Tensile Properties of Annealed Be-38% Al Alloy Extrusions as a Function of Exposure Time at 400° F (Strain rate: .005/min to T.Y.S., .08/min to T.S.)

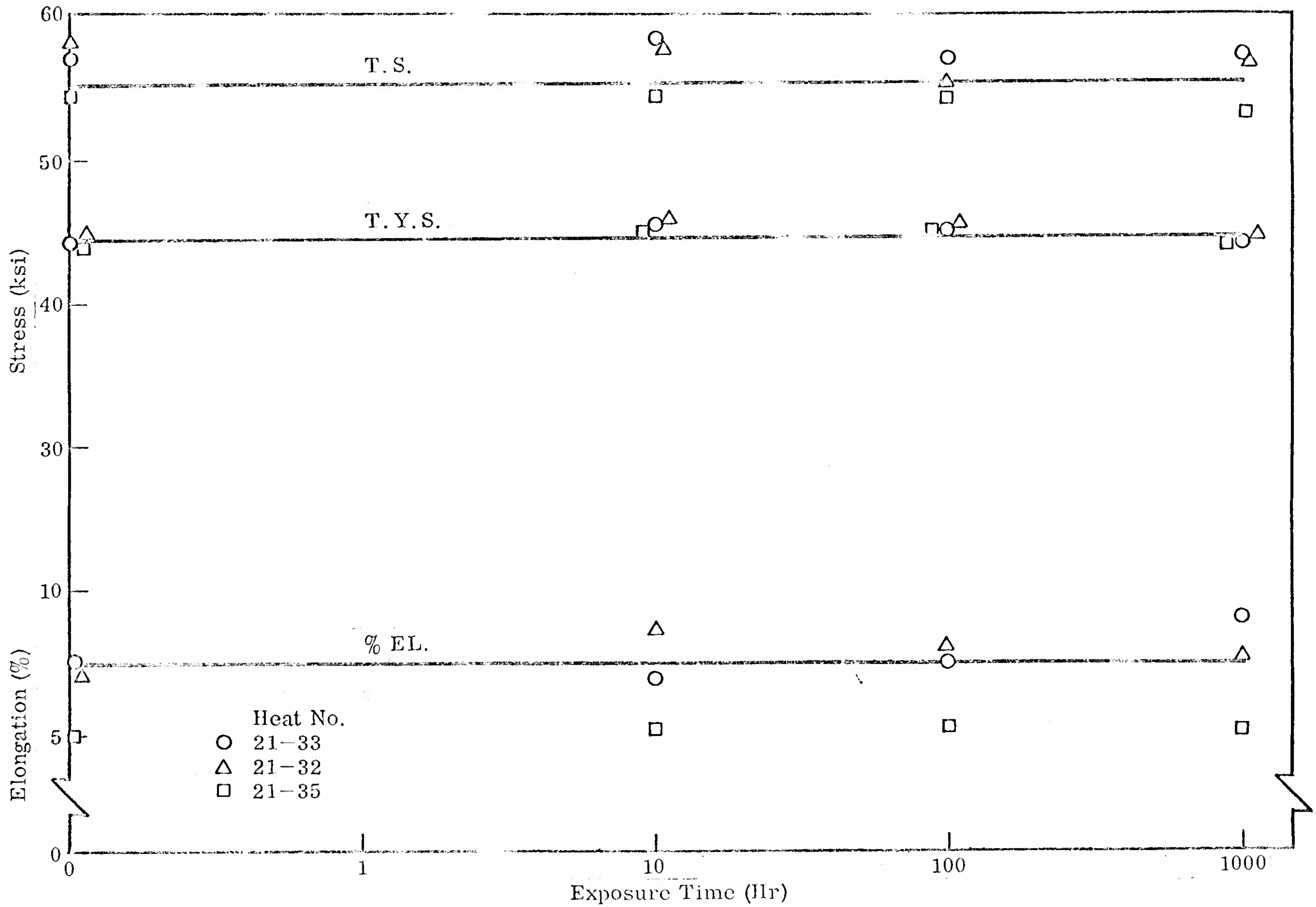


Fig. 7 Longitudinal 75°F Tensile Properties of Annealed Be-38% Al Alloy Extrusions as a Function of Exposure Time at 800°F (Strain rate: .005/min to T.Y.S., .08/min to T.S.)

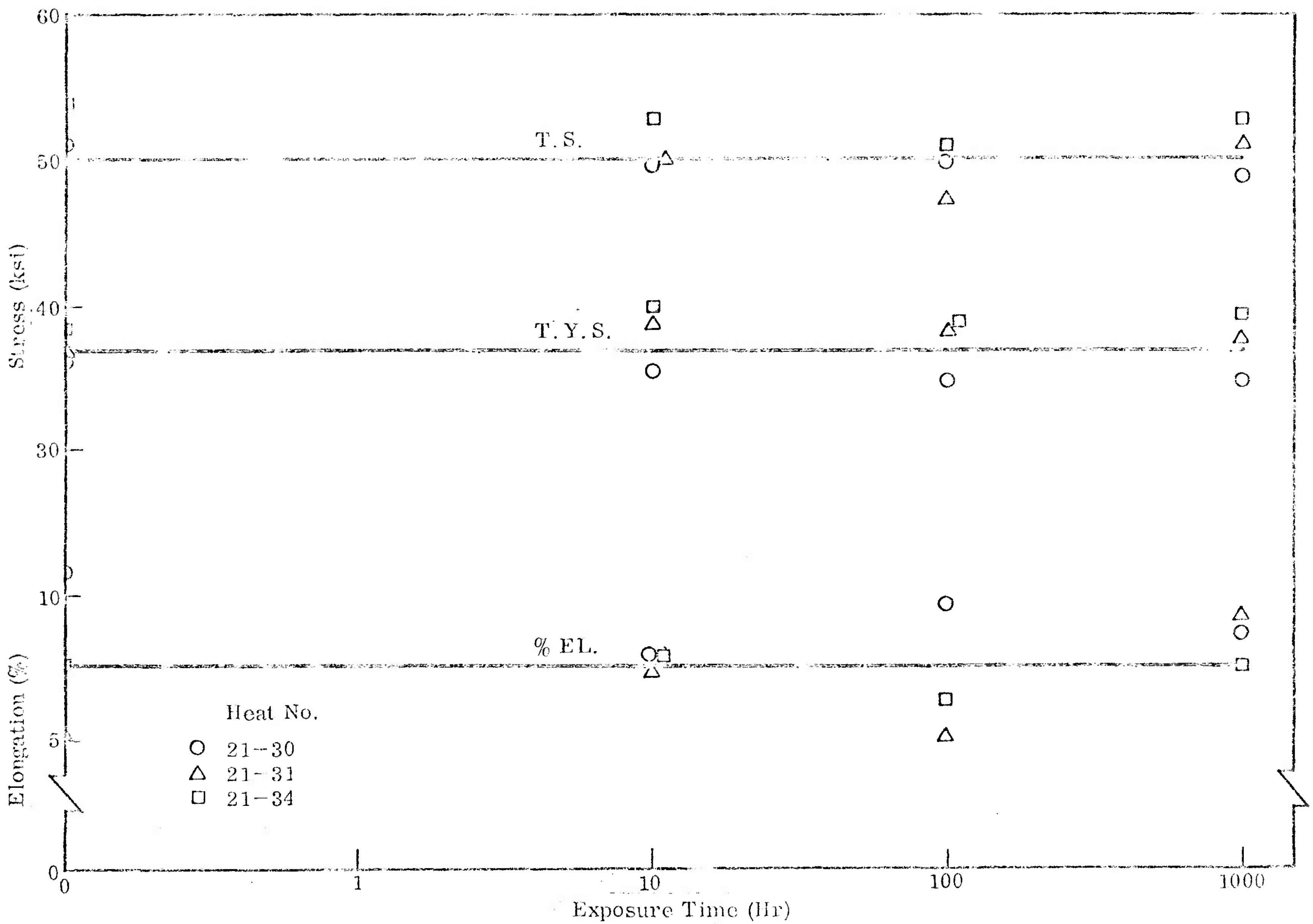


Fig. 8 Longitudinal 75° F Tensile Properties of Annealed 0.060-in.-thick Be-38% Al Alloy Sheet as a Function of Exposure Time at 400° F (Strain rate: .005/min to T. Y. S., .08/min to T. S.)

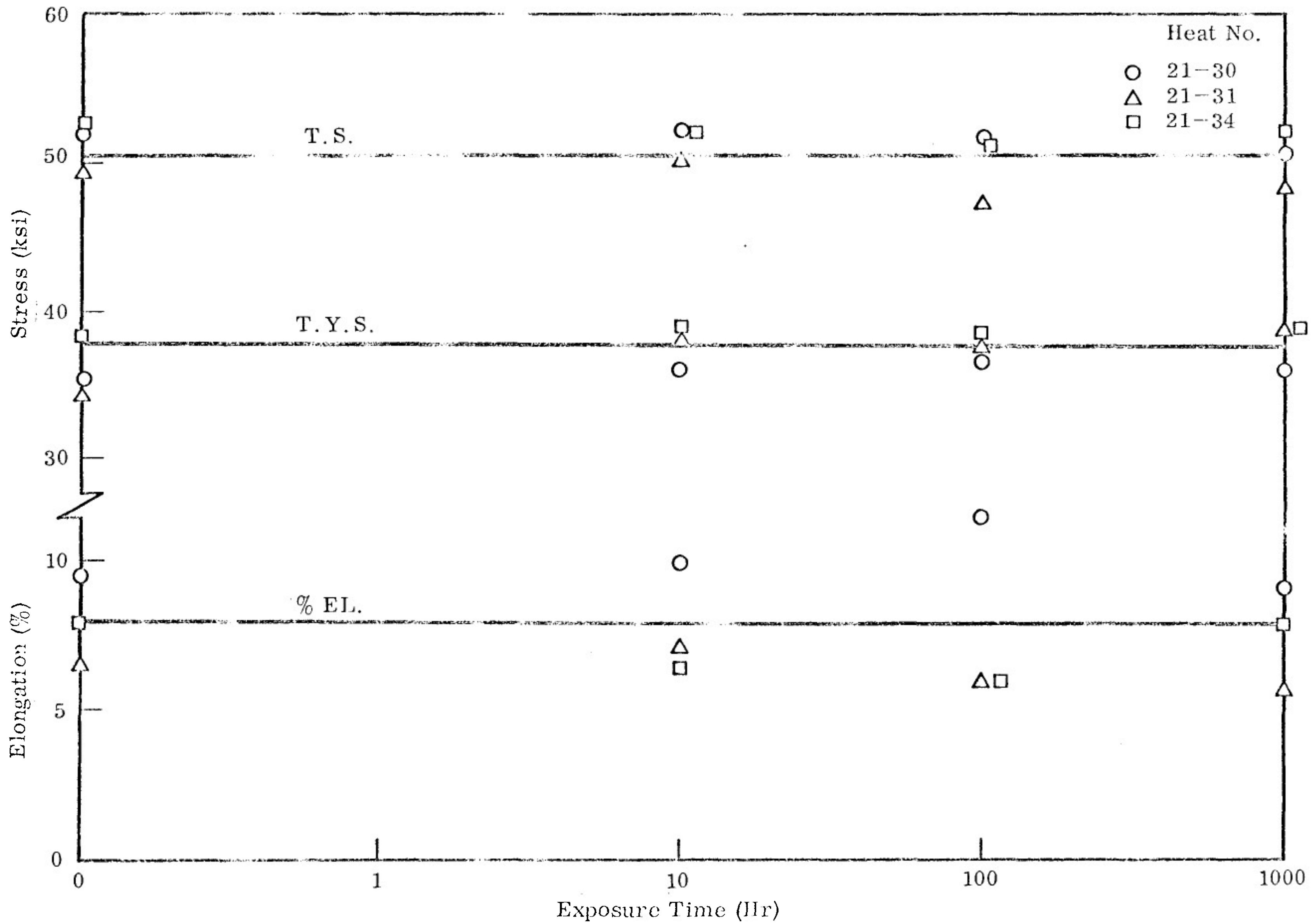


Fig. 9 Transverse 75° F Tensile Properties of Annealed 0.060-in.-thick Be–38% Al Alloy Sheet as a Function of Exposure Time at 400° F (Strain rate: .005/min to T. Y. S., .08/min to T. S.)

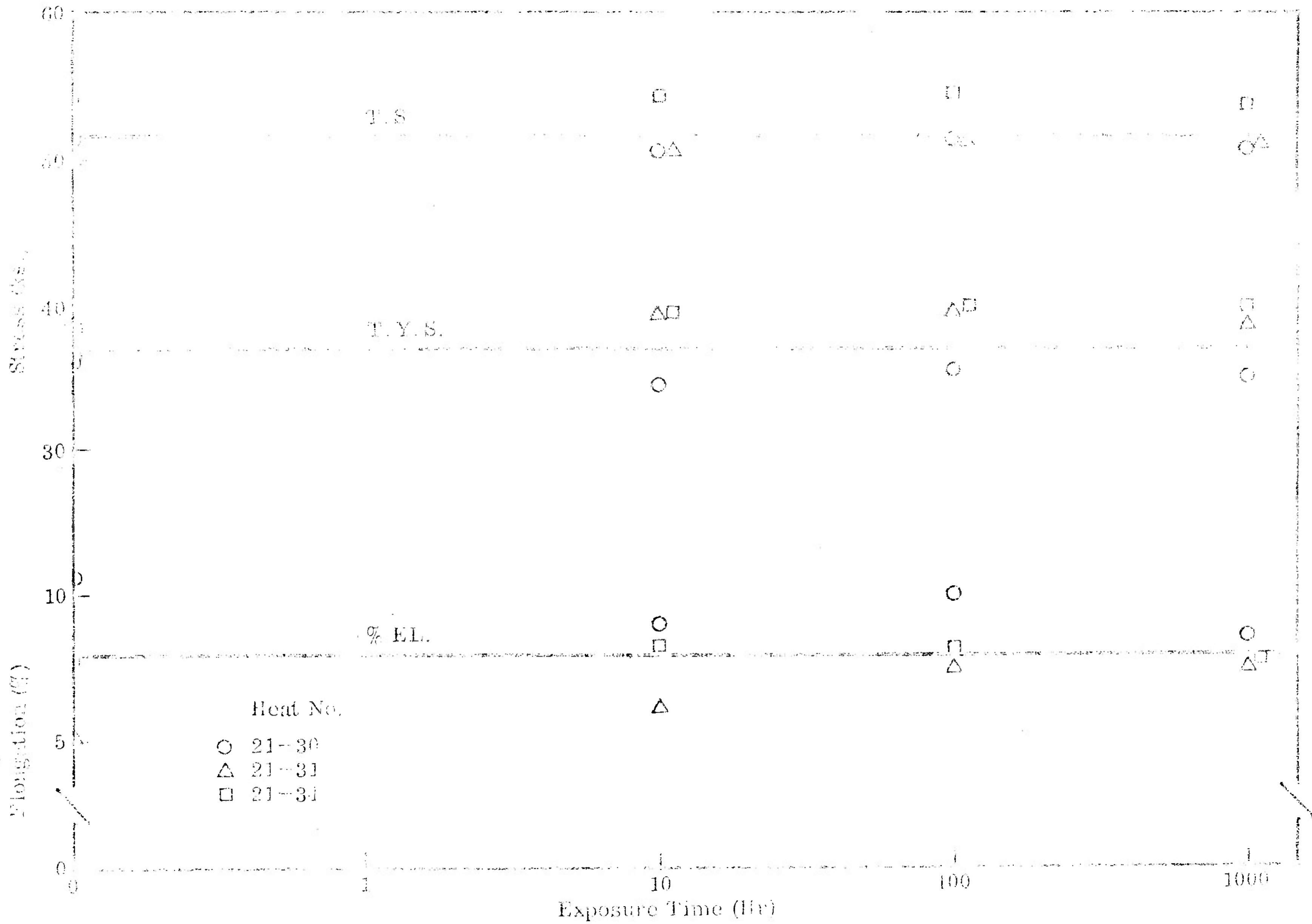


Fig. 10 Longitudinal 75°F Tensile Properties of Annealed 0.060-in.-thick Be-38% Al Alloy Sheet as a Function of Exposure Time at 800°F (Strain rate: .005/min to T.Y.S., .08/min to T.S.)

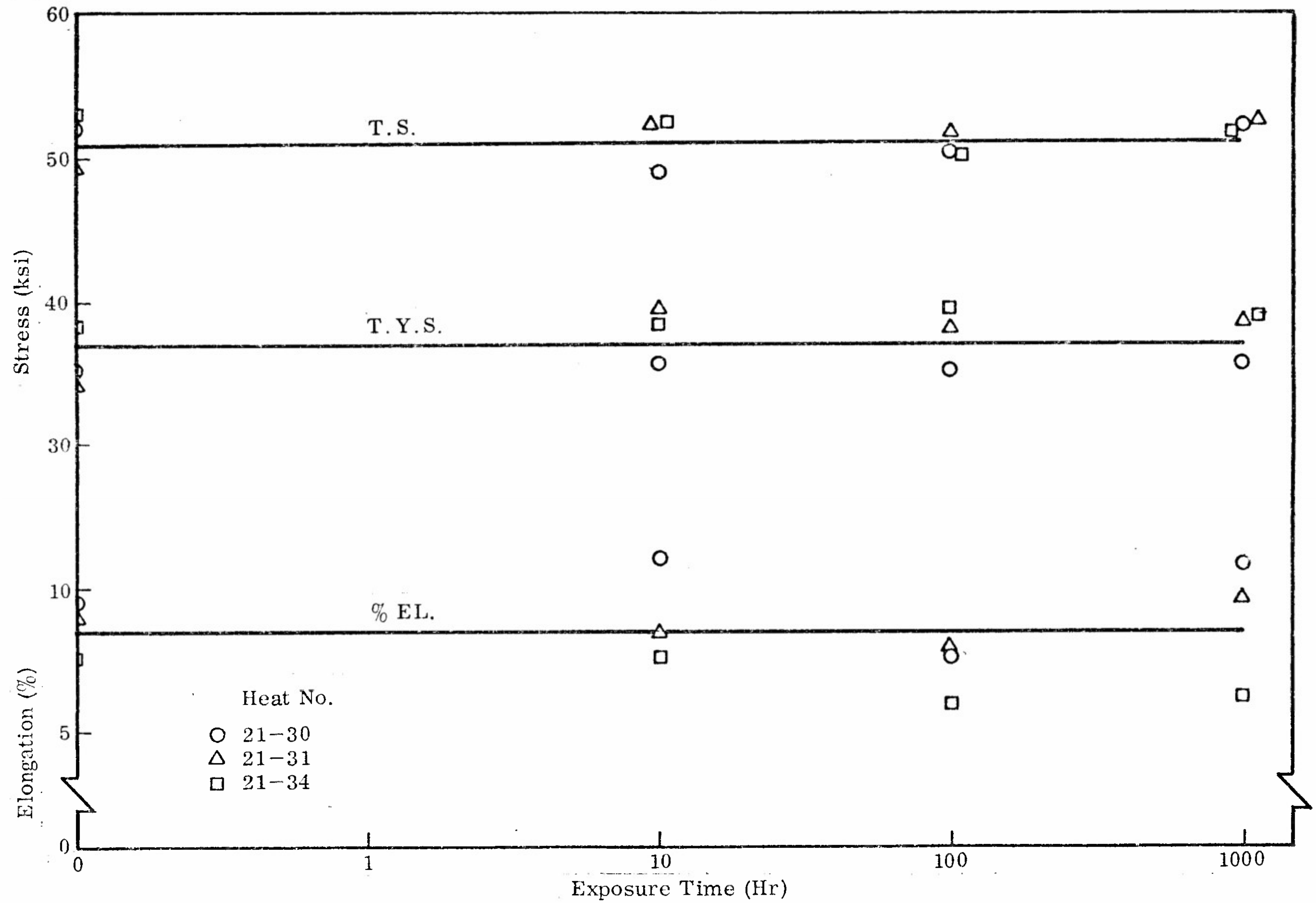


Fig. 11 Transverse 75°F Tensile Properties of Annealed 0.060-in.-thick Be-38% Al Alloy Sheet as a Function of Exposure Time at 800°F (Strain rate: .005/min to T.Y.S., .08/min to T.S.)

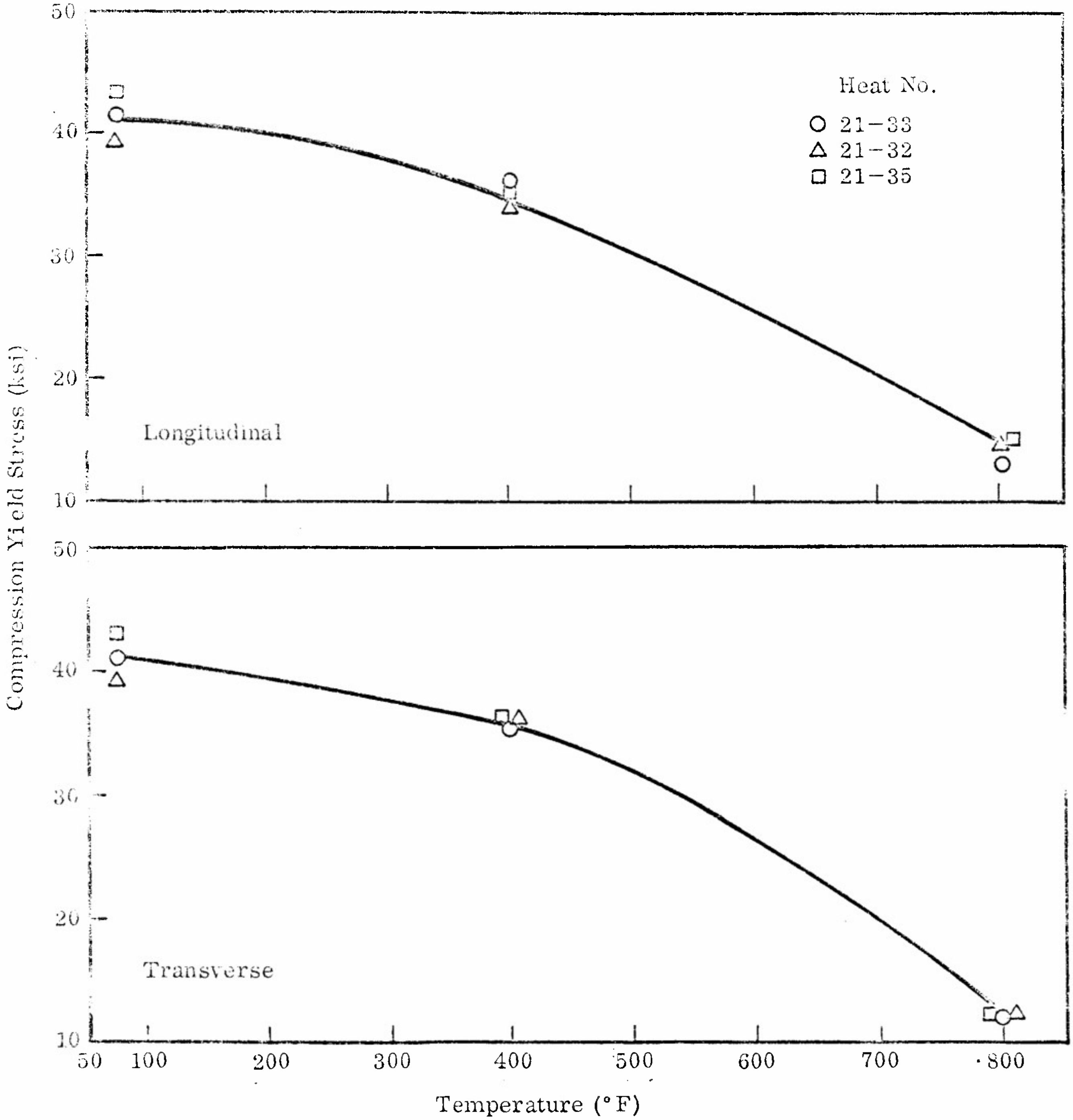


Fig. 12 Compression Yield Strength of Annealed Be-38% Al Alloy Extrusions as a Function of Temperature (Strain rate: .005/min)

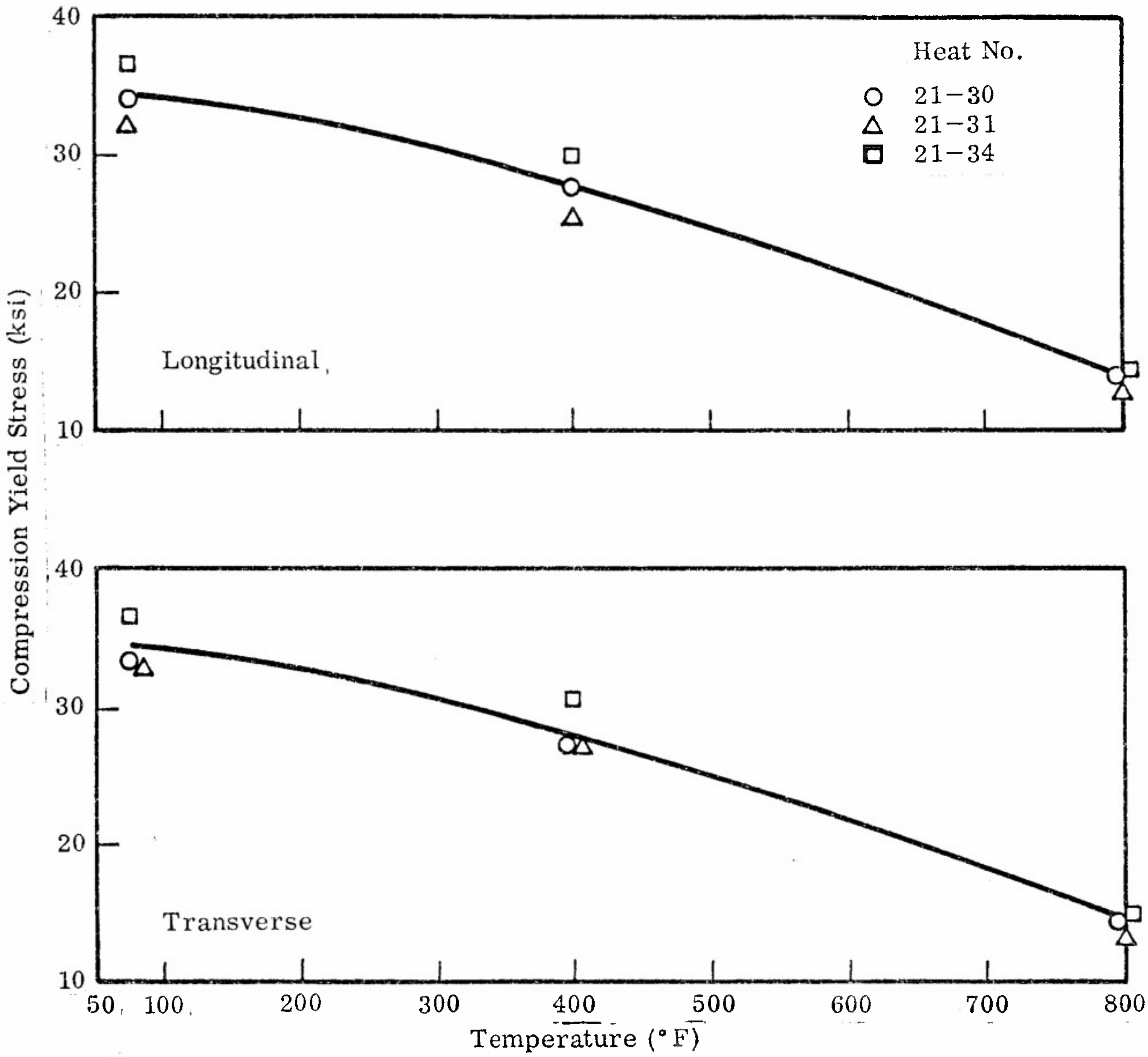


Fig. 13 Compression Yield Strength of Annealed 0.060-in.-thick Be-38% Al Alloy Sheet as a Function of Temperature (Strain rate: .005/min)

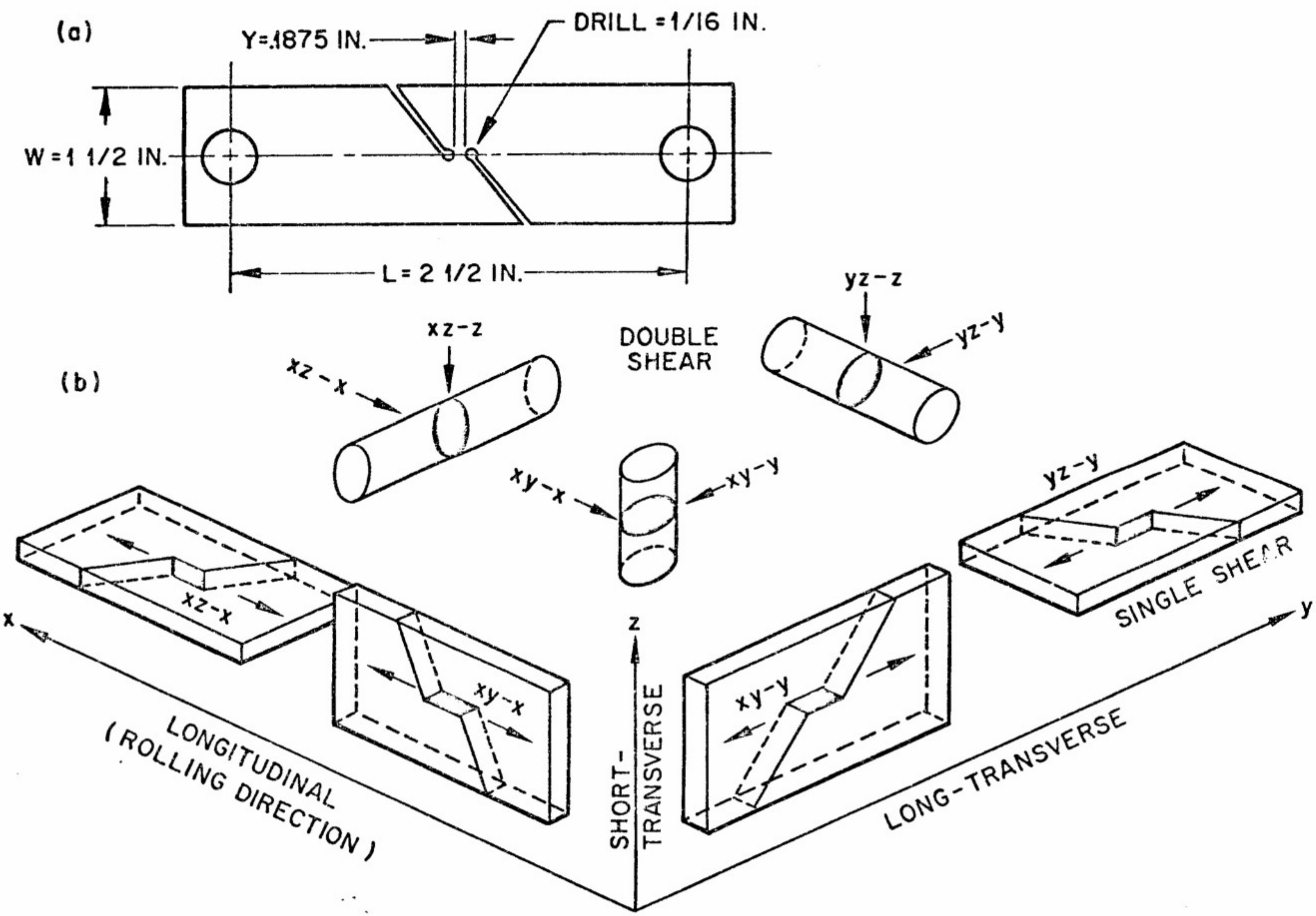


Fig. 14 Shear Test Specimens and Orientations
(a) Sheet-Shear Test Specimen
(b) Schematic Drawing Showing Types of Shear Tests, Shear Planes and Directions (After Kaufman and Davies – Ref. 14)

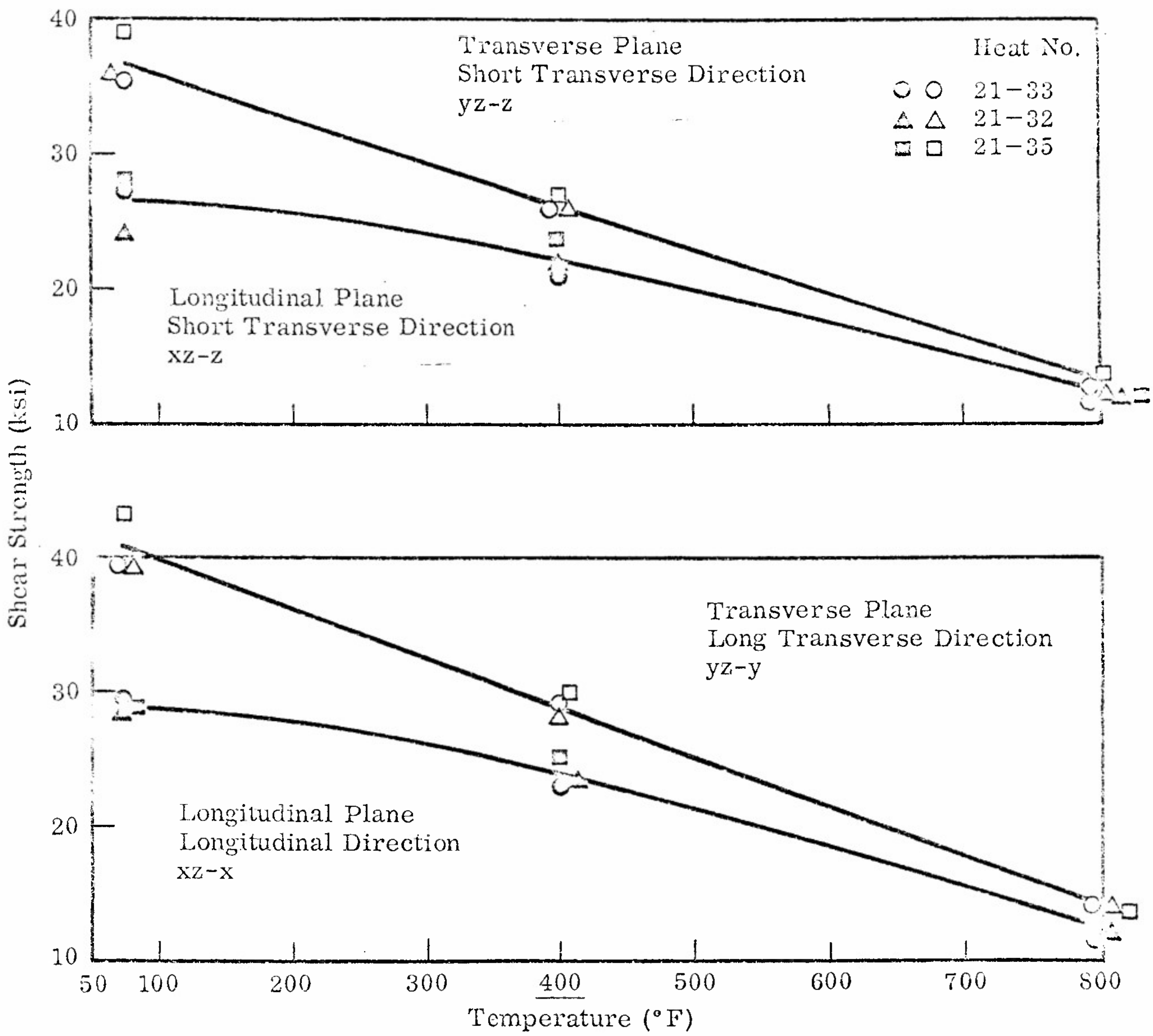


Fig. 15 Shear Strength of Annealed Be-38% Al Alloy Extrusions as a Function of Temperature (Pin-double-shear method, 0.125-in. -diam. test specimens 0.1 in./min cross head rate)

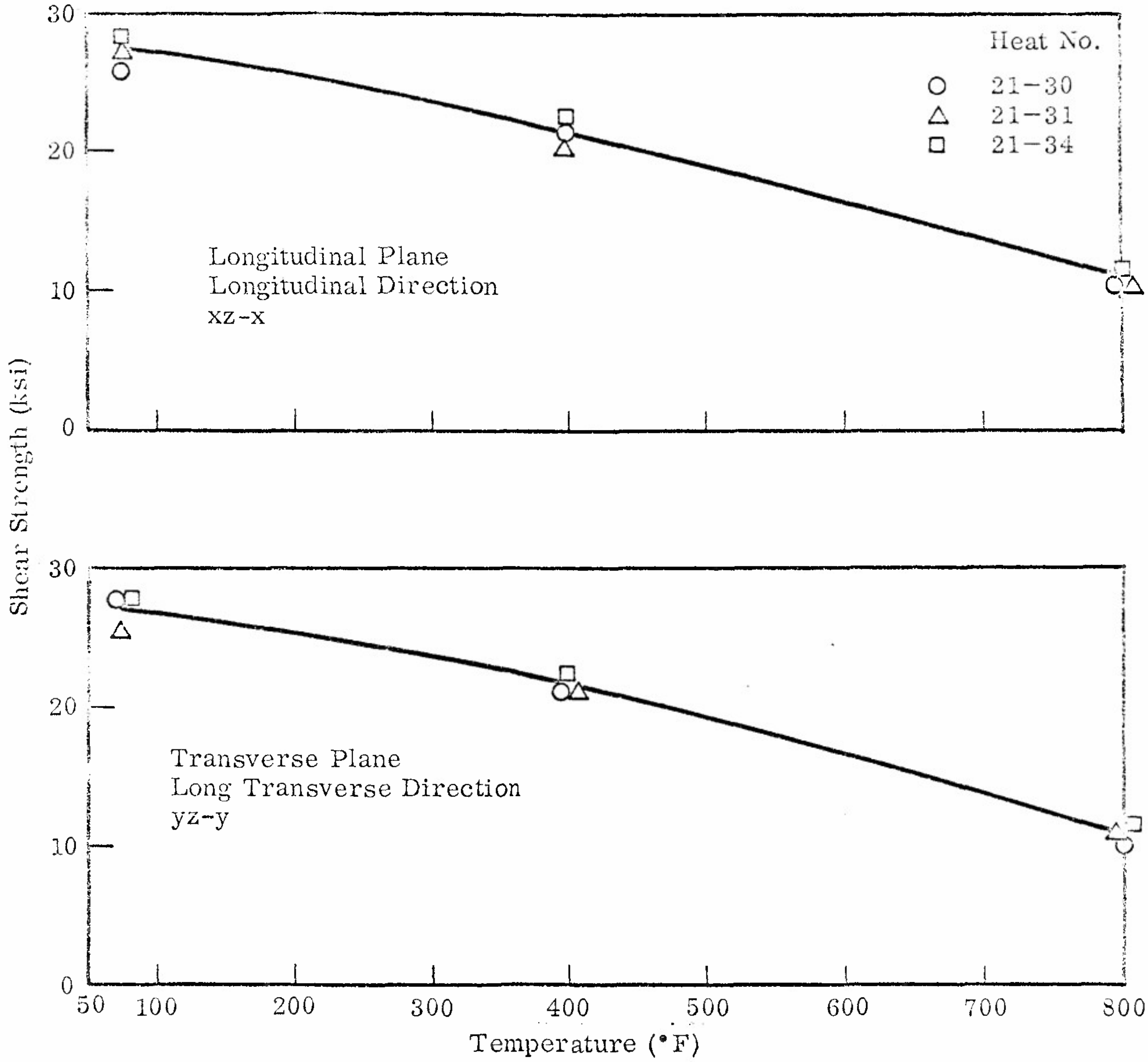


Fig. 16 Shear Strength of Annealed 0.060-in. -thick Be-38% Al Alloy Sheet as a Function of Temperature (Sheet-single-shear technique, 0.01 in./min cross head rate)

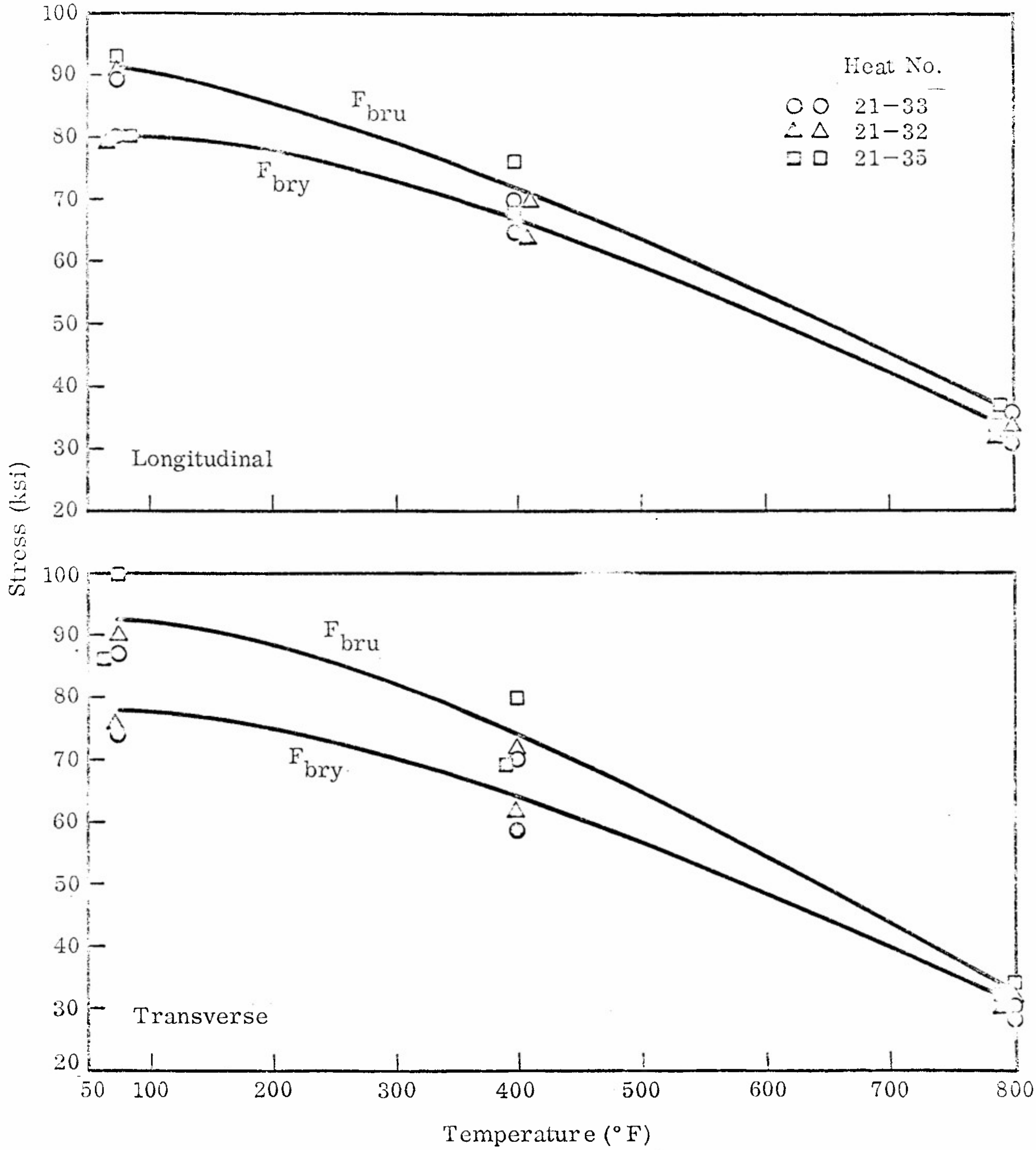


Fig. 17 Bearing Strength Properties of Annealed Be-38% Al Alloy Extrusions as a Function of Temperature (e/D = 2, 3/16-in. -diam. pin, 0.01 in./min cross head rate)

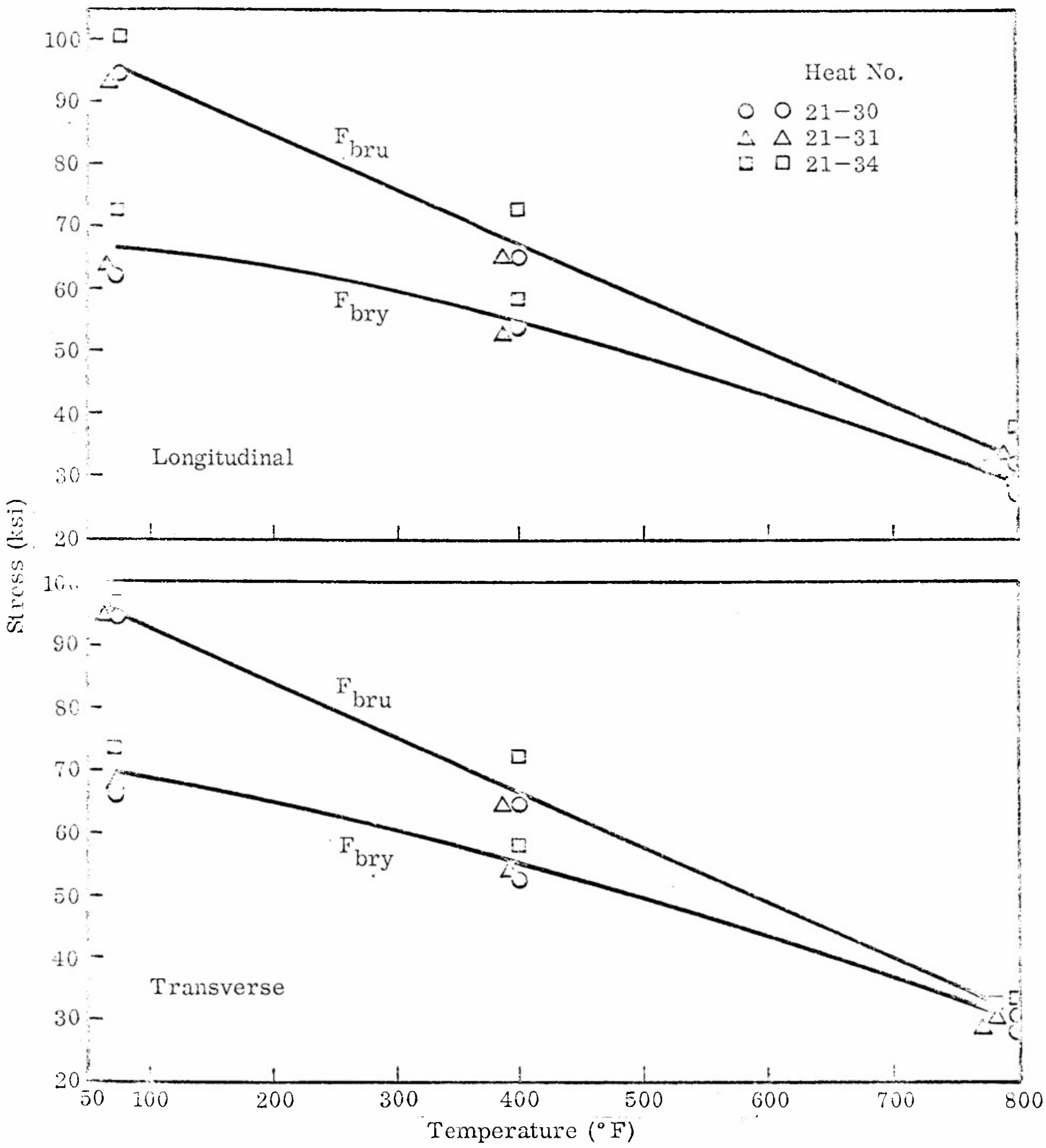


Fig. 18 Bearing Strength Properties of Annealed 0.060-in.-thick Be-38% Al Alloy Sheet as a Function of Temperature (e/D = 2, 0.01 in./min cross head rate)

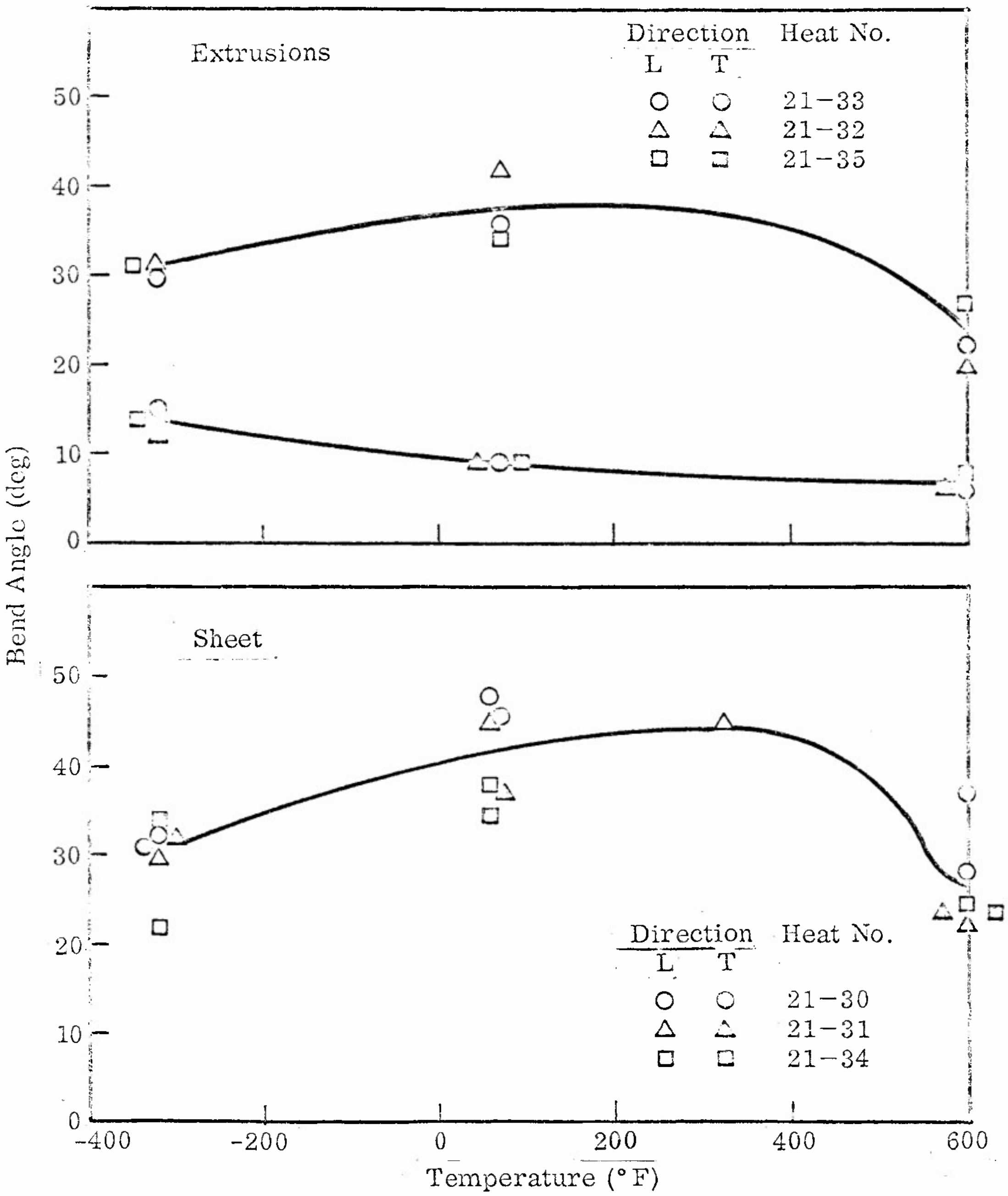


Fig. 19 Bend Angle of Annealed Be-38% Al Alloy Sheet and Extrusion as a Function of Temperature (3 point bend, 1.5-in. span, 0.25-in. radius mandrel, 0.1-in./min cross head rate, 1-in. -width specimens etched to 0.054-in. thickness)

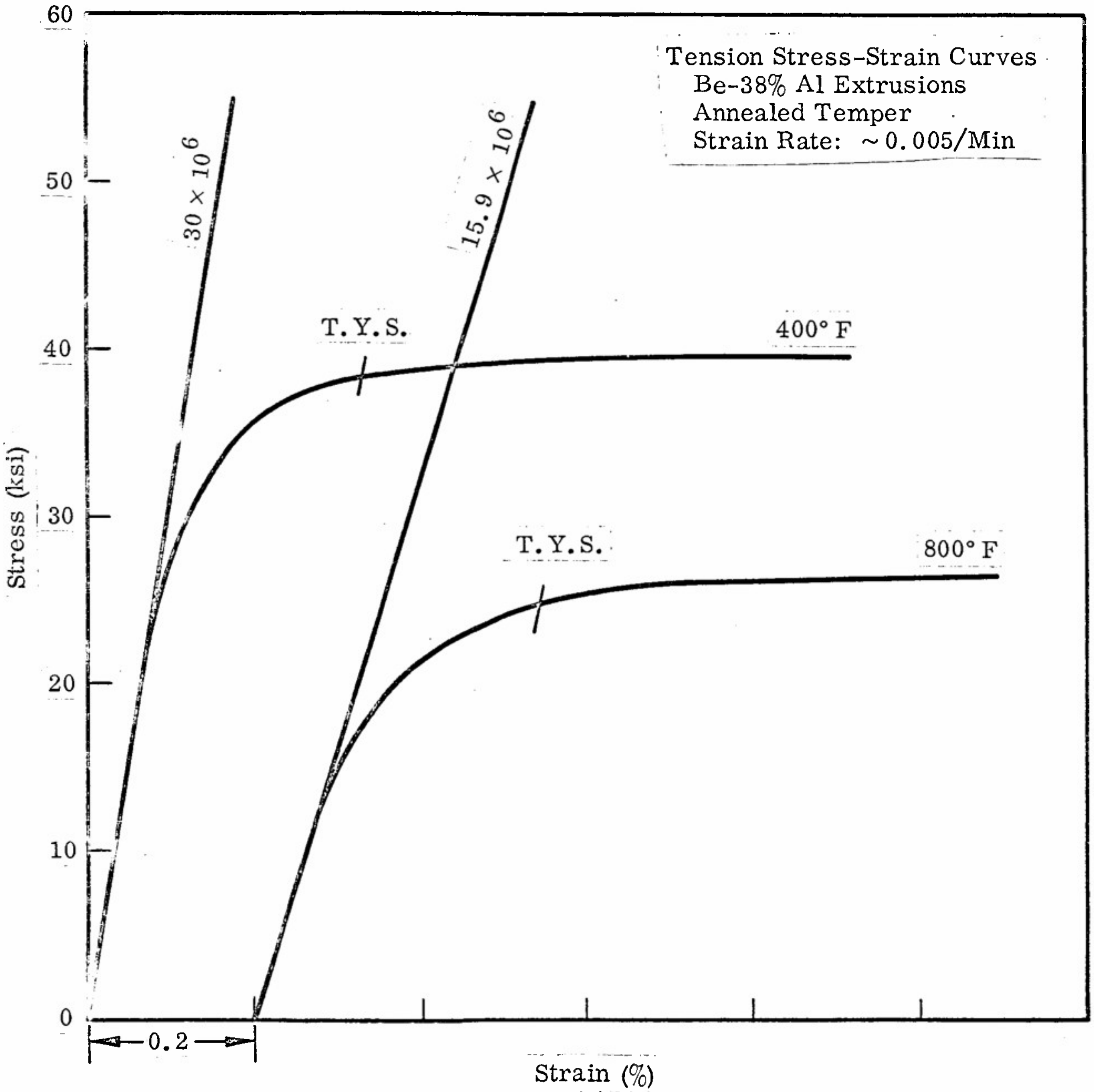


Fig. 21 Tensile Stress Strain Curves at 400 and 800°F for Annealed Be-38% Al Alloy Extrusions in the Longitudinal and Transverse Directions

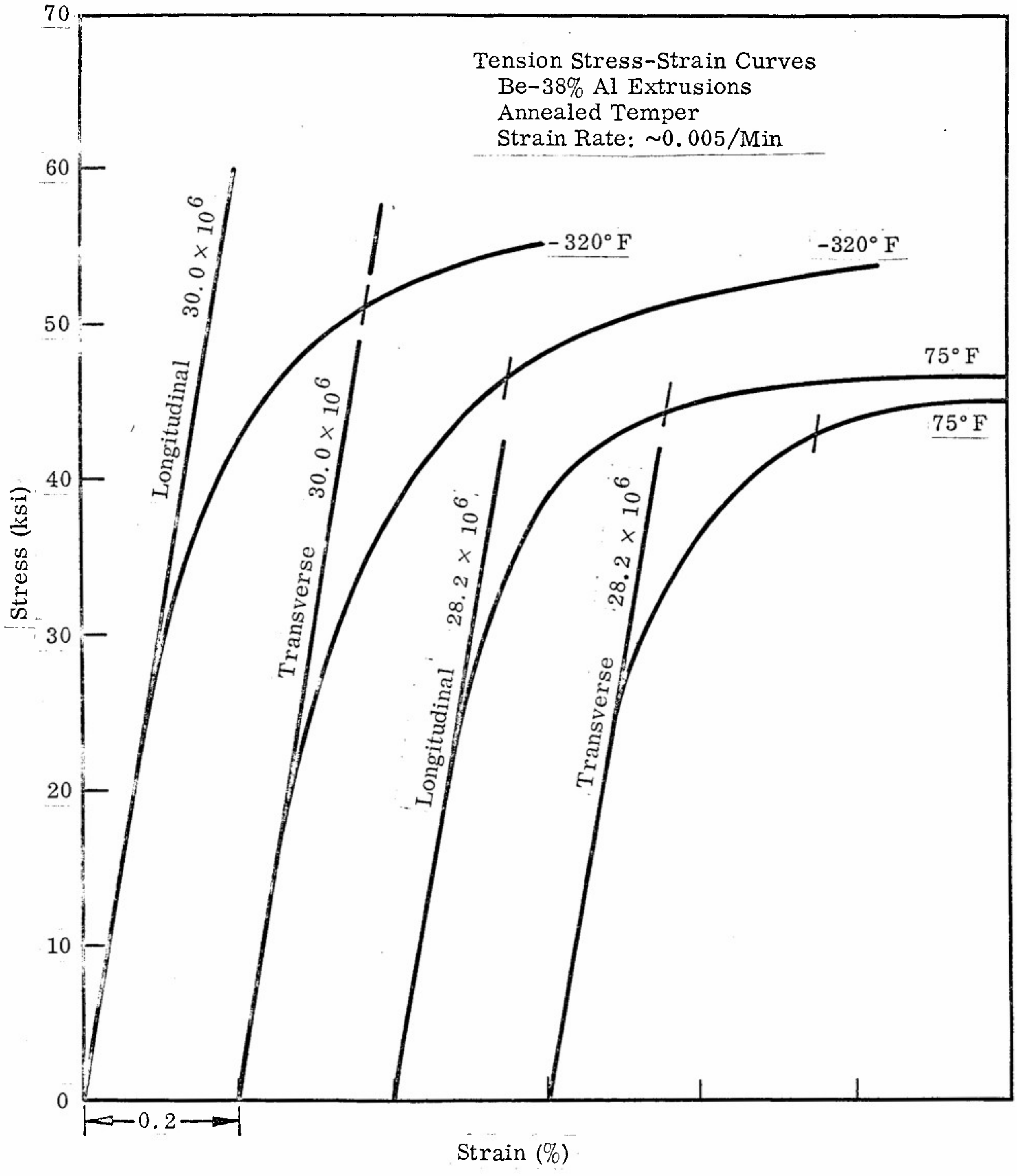


Fig. 20 Tensile Stress-Strain Curves at −320 and 75°F for Annealed Be-38% Al Alloy Extrusions

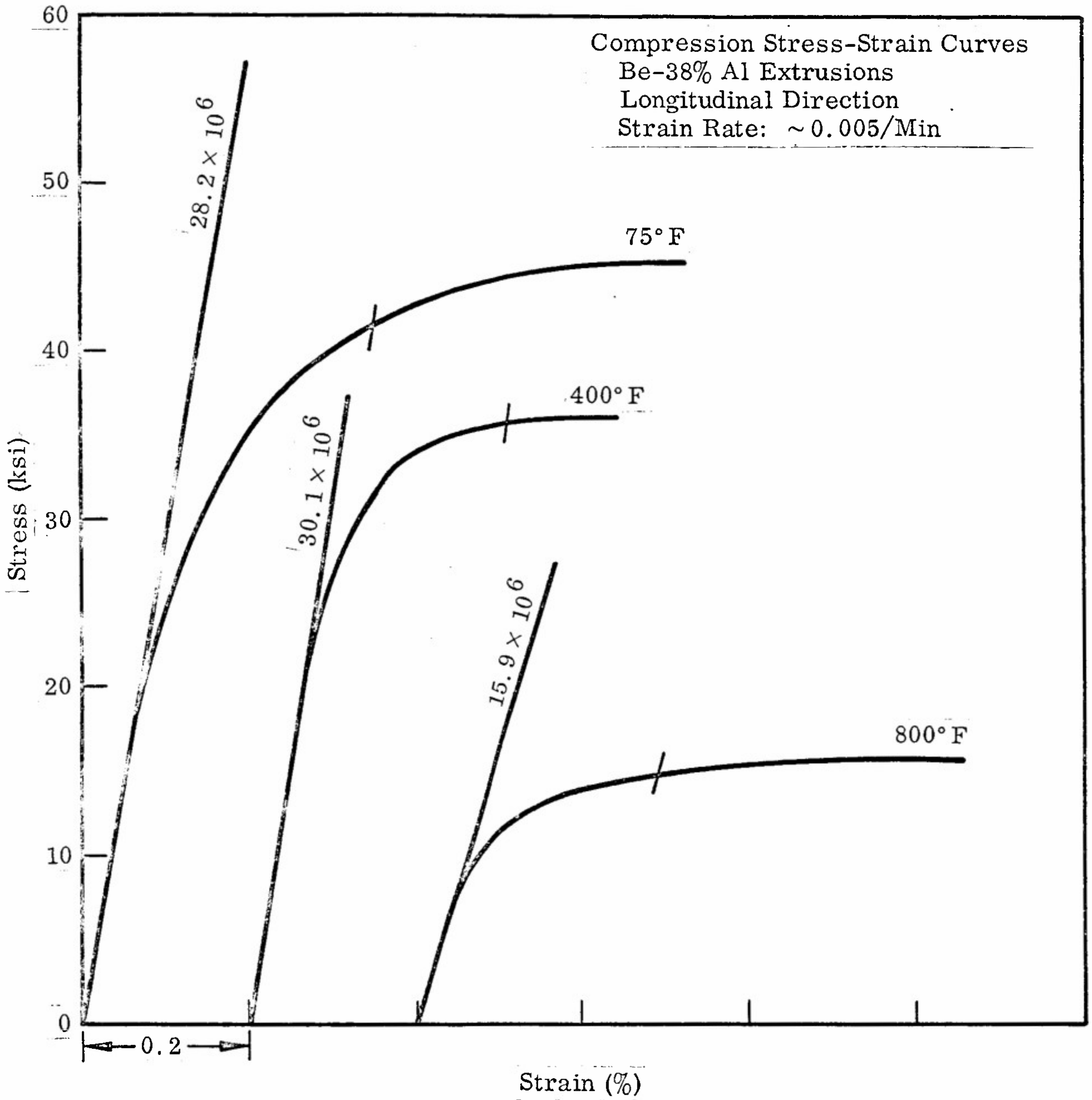


Fig. 22 Compression Stress-Strain Curves at 75, 400 and 800°F for Annealed Be-38% Al Alloy Extrusions in the Longitudinal Direction

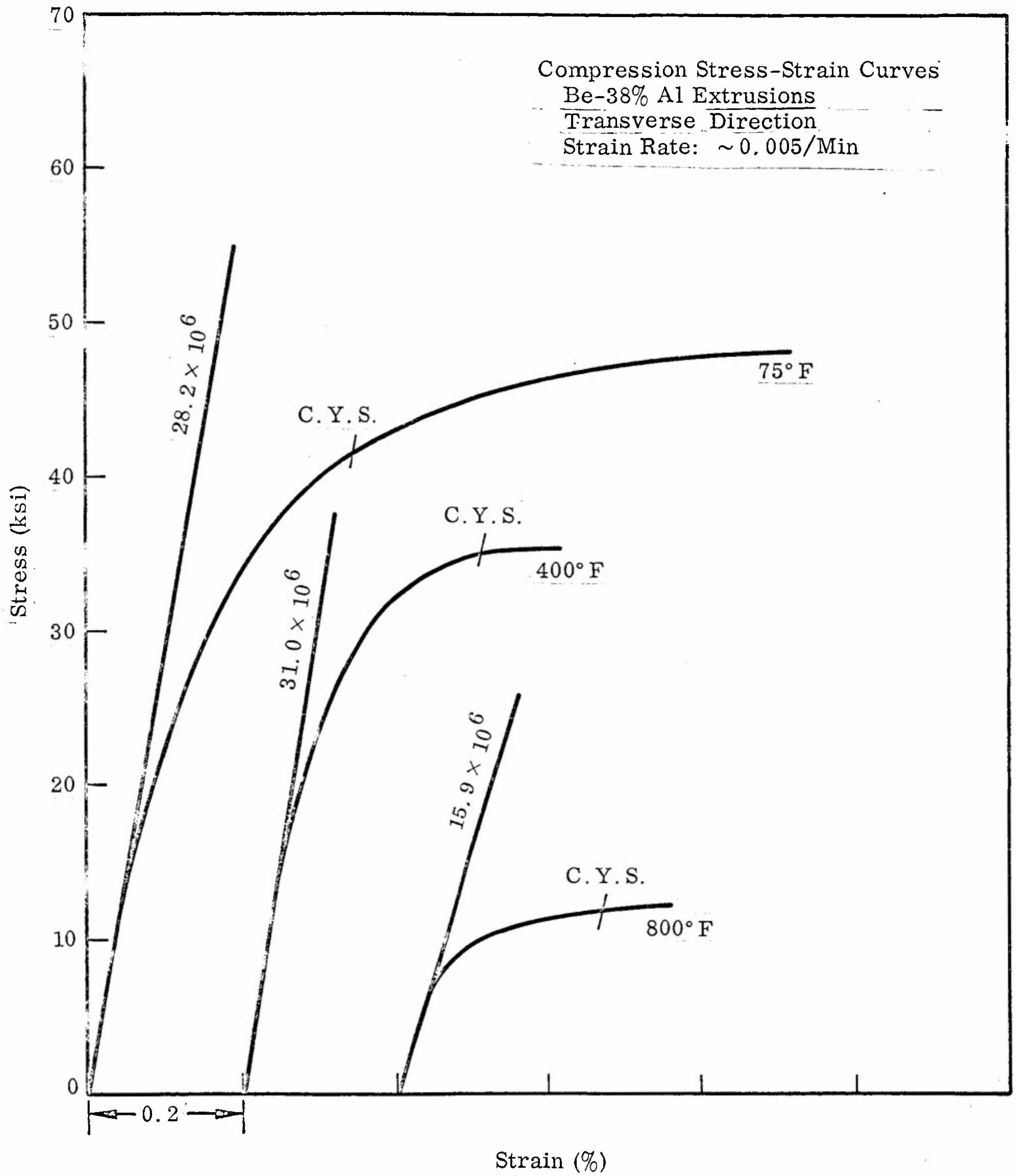


Fig. 23 Compression Stress-Strain Curves at 75, 400, and 800°F for Annealed Be-38% Al Extrusions in the Transverse Direction

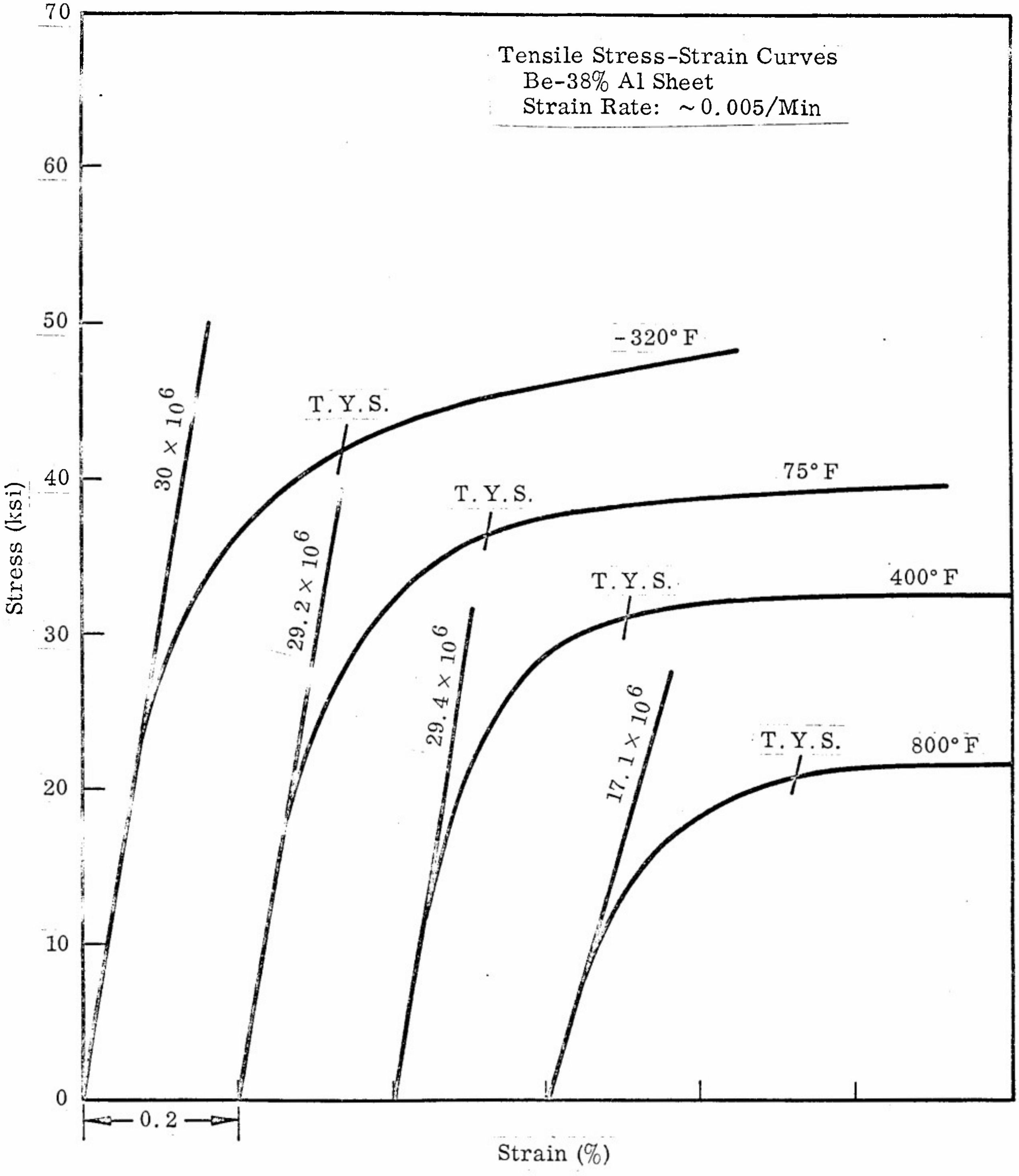


Fig. 24 Tensile Stress-Strain Curves at -320, 75, 400 and 800°F for Annealed Be-38% Al Sheet in the Longitudinal and Transverse Directions

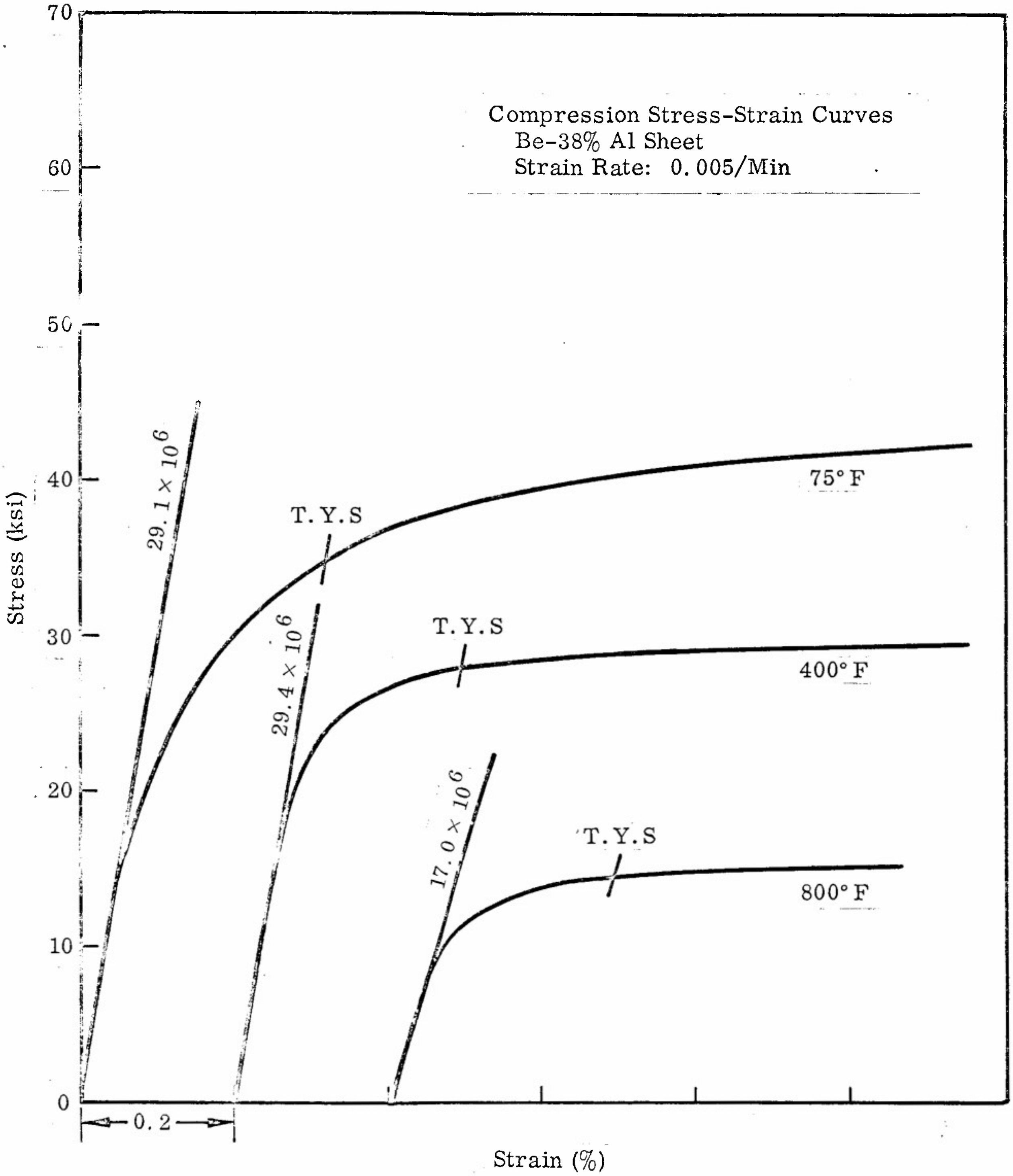
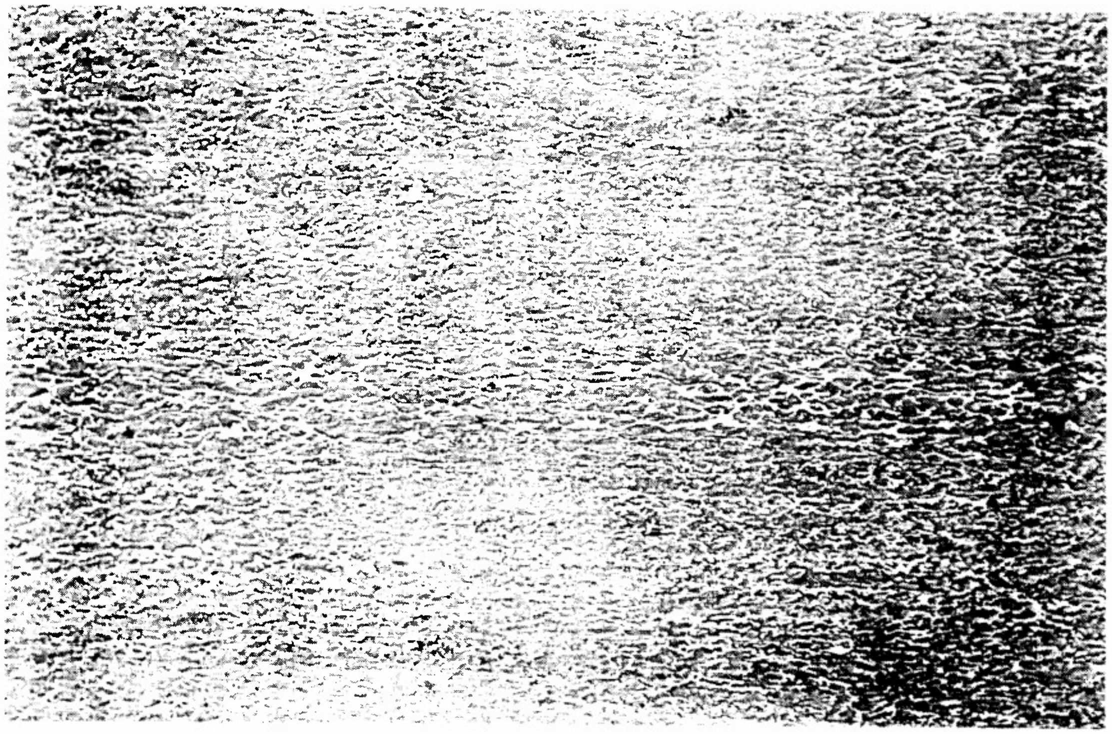


Fig. 25 Compression Stress-Strain Curves at 75, 400, and 800°F for Annealed Be-38% Al Sheet in the Longitudinal and Transverse Directions



(a) M-8873 As-Polished 100×

(b) M-8875 As-Polished 100×

Fig. 26 Microstructure of Be-38% Al Annealed Extrusion (21-33-5A, center)
(a) Longitudinal Section
(b) Transverse Section. Black features tentatively identified as Beryllium Carbide.

(a) M-8940 As-Polished 1000×

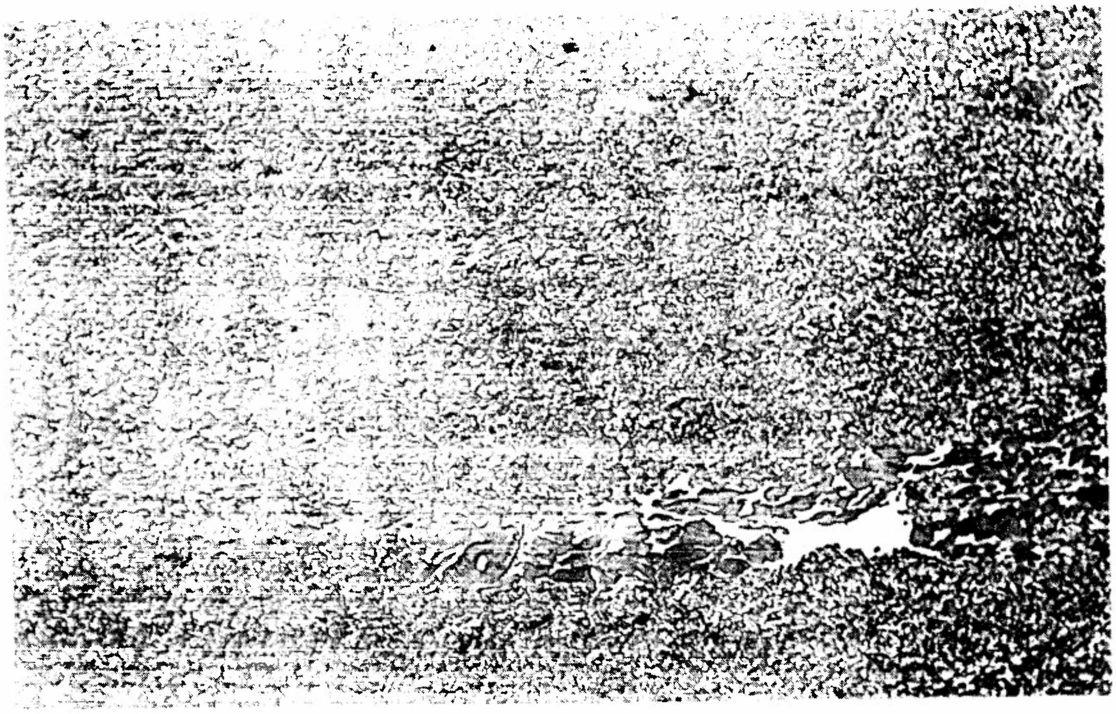
(b) M-8941 As-Polished 1000×

Fig. 27 Microstructure of Be-38% Al Annealed Extrusion (21-32-2A-16)
(a) Longitudinal Section
(b) Transverse Section

(a) M-8862 As-Polished 100×

(b) M-8864 As-Polished 100×

Fig. 28 Microstructure of Be-38% Al Annealed Extrusion (21-35-307-14)
(a) Longitudinal Section Showing Tensile Fracture Surface
(b) Transverse Section

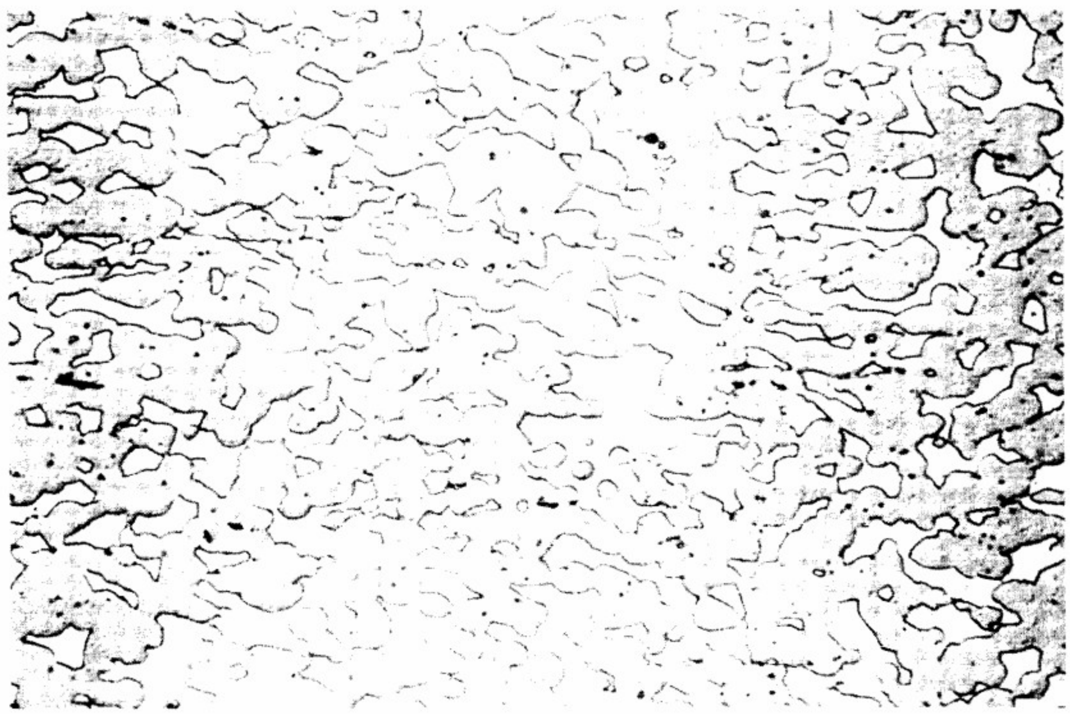


(a) M-8871 As-Polished 100×

(b) M-8575 Etched 1000×

Fig. 29 (a) Transverse Section of Annealed Be-38% Al Extrusion (21-32, 2A-16) Showing Aluminum Segregation
(b) Longitudinal Section of Annealed Be-38% Al Sheet (21-31, 2C-5L) Showing Severe Scratches and Imbedded Grit from Grinding Operation

M-8572 3448 100X



M-8573 3448 1000X

Fig. 30 Microstructure of Etched Be-38% Al Sheet (21-31, 2C-5L). (Representative of both longitudinal and transverse sections of heats 21-30, 21-31 and 21-34.)

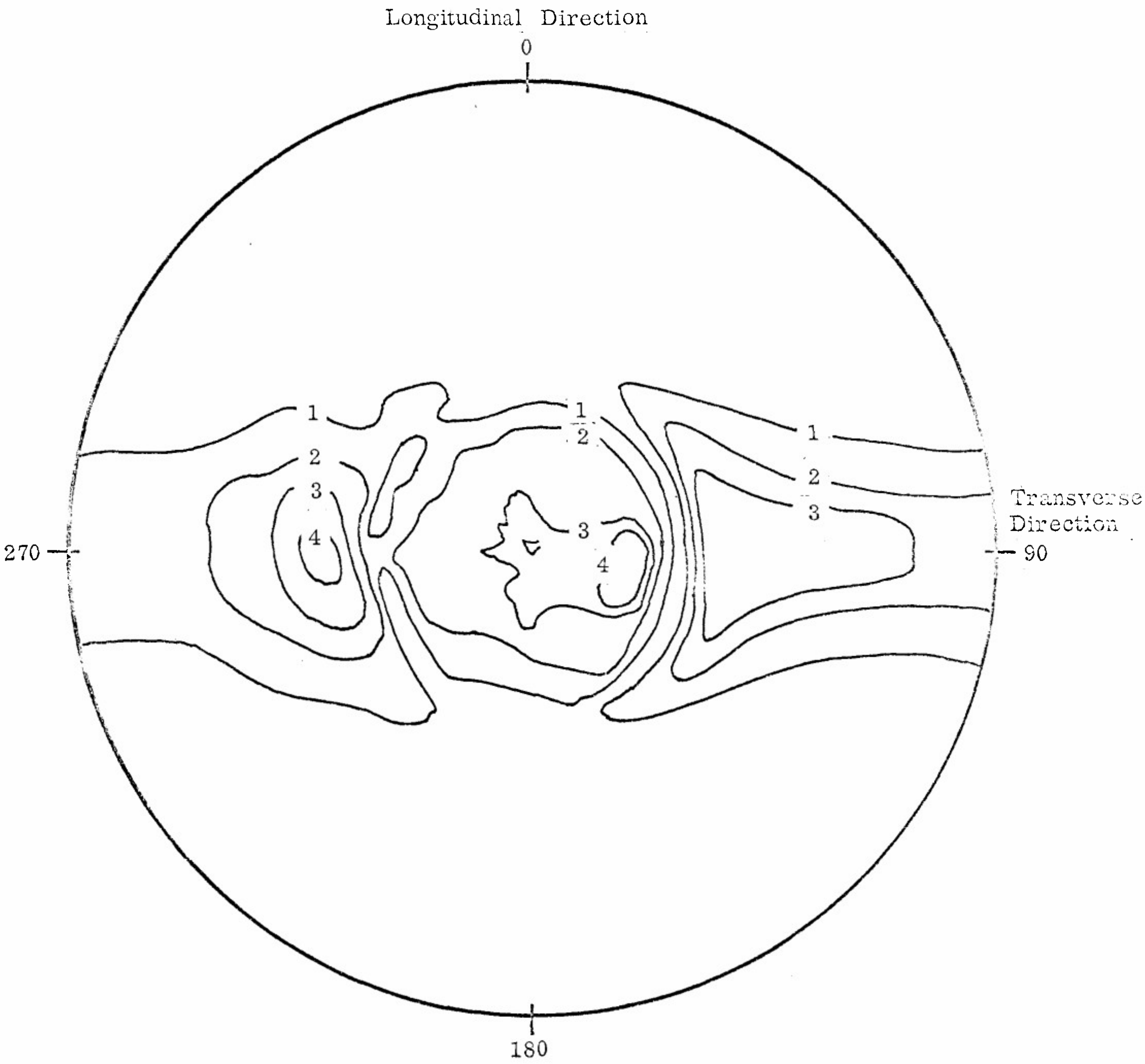


Fig. 31 Be (0002) Basal Pole Figure for Be-38% Al Extrusion 21-33-5B
(Numbers represent intensities times random)

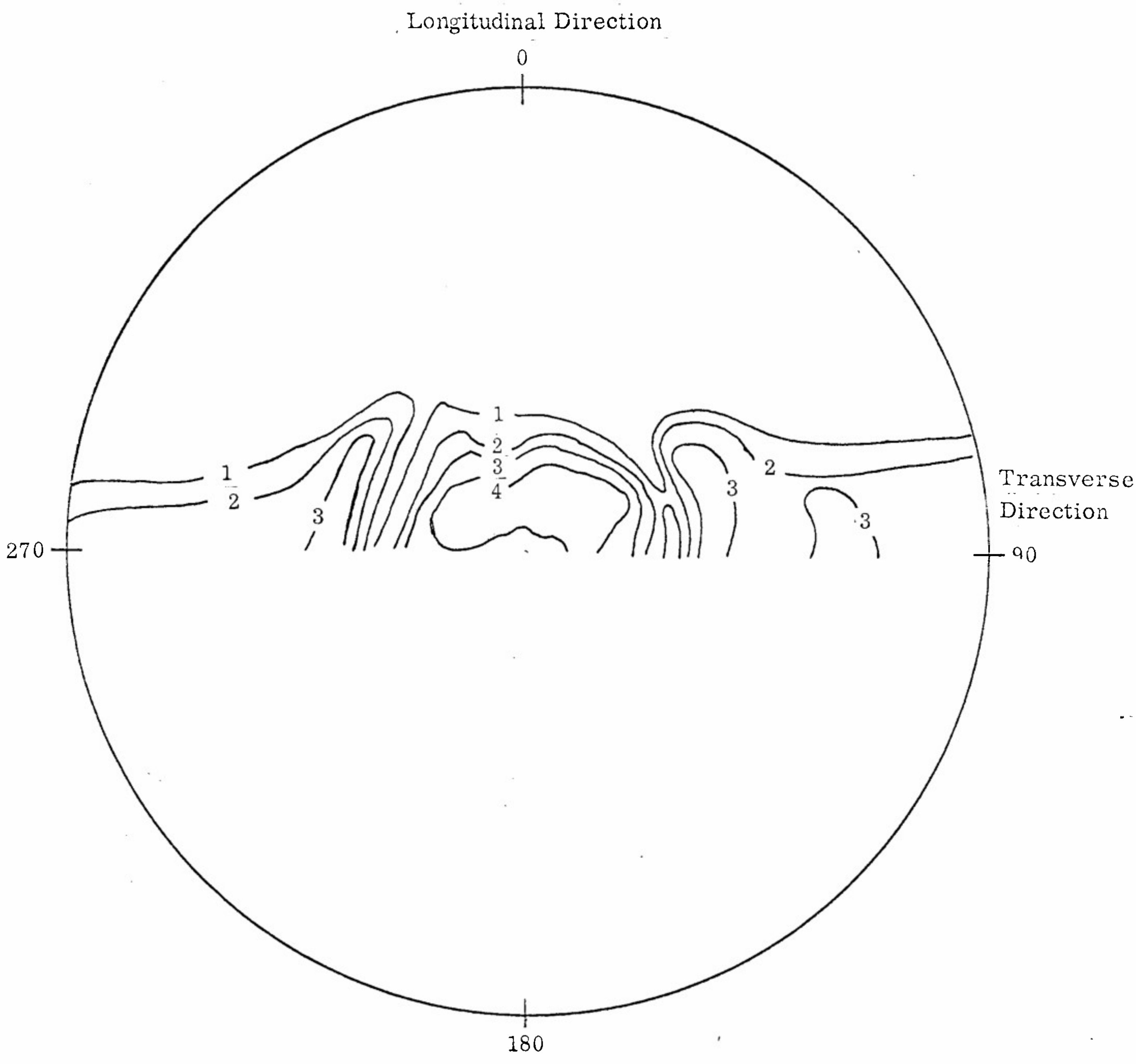


Fig. 32 Be (0002) Basal Pole Figure for Be-38% Al Extrusion 21-32-8
(Numbers represent intensities times random)

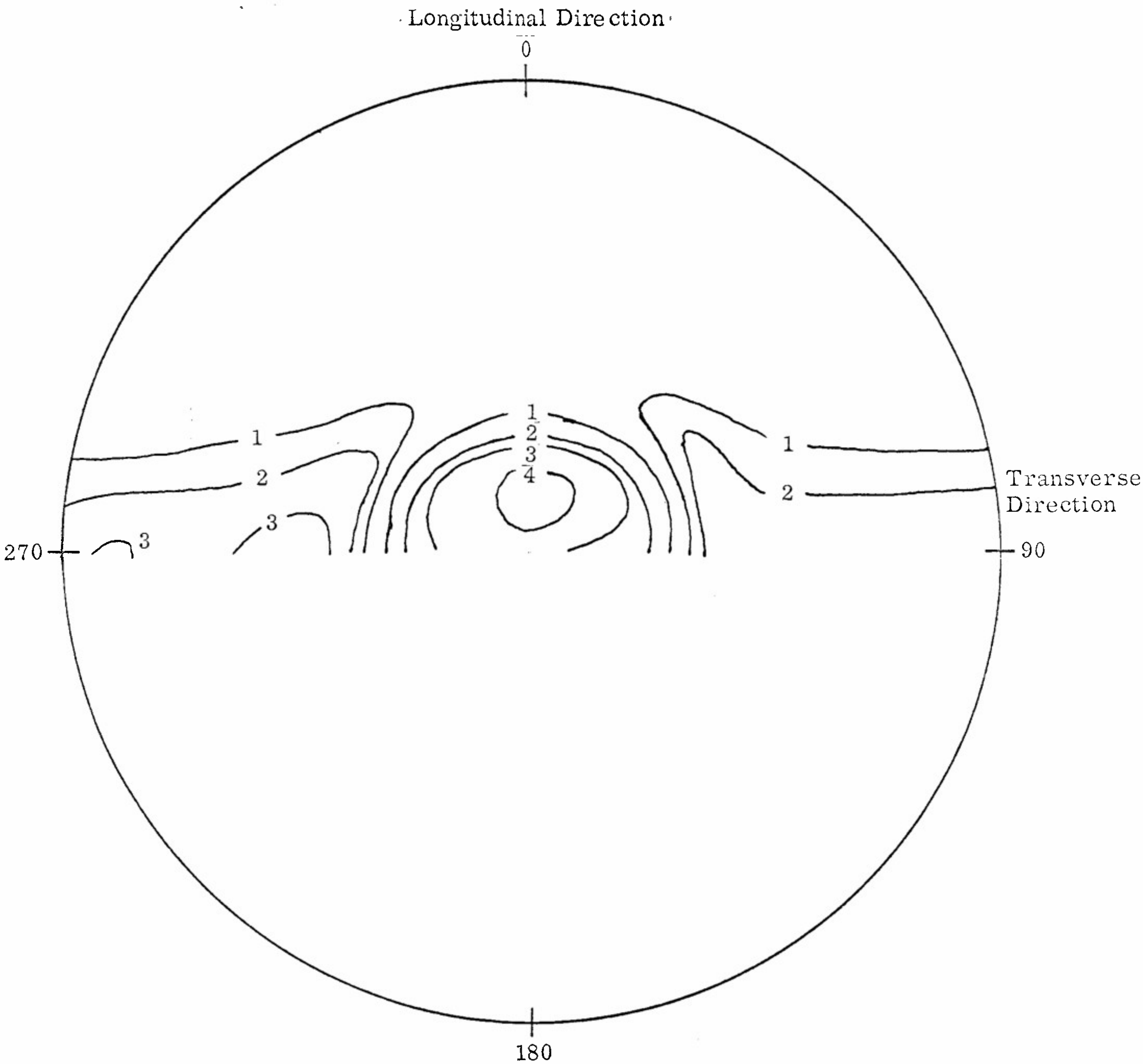


Fig. 33 Be (0002) Basal Pole Figure for Be-38% Al Extrusion 21-35-307
(Numbers represent intensities times random)

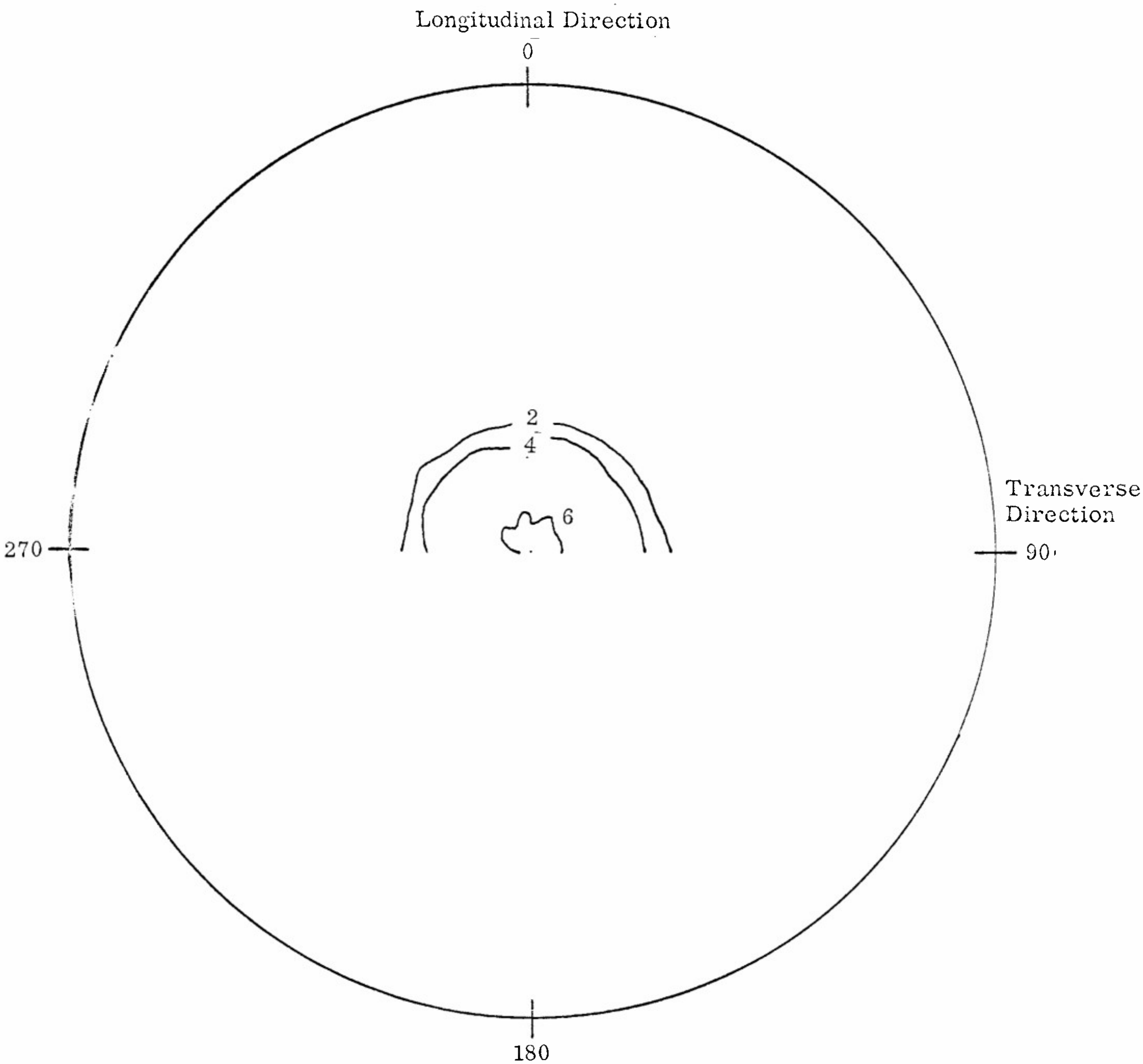


Fig. 34 Be (0002) Basal Pole Figure for Be-38% Al Sheet 21-30-3B
(Numbers represent intensities times random)

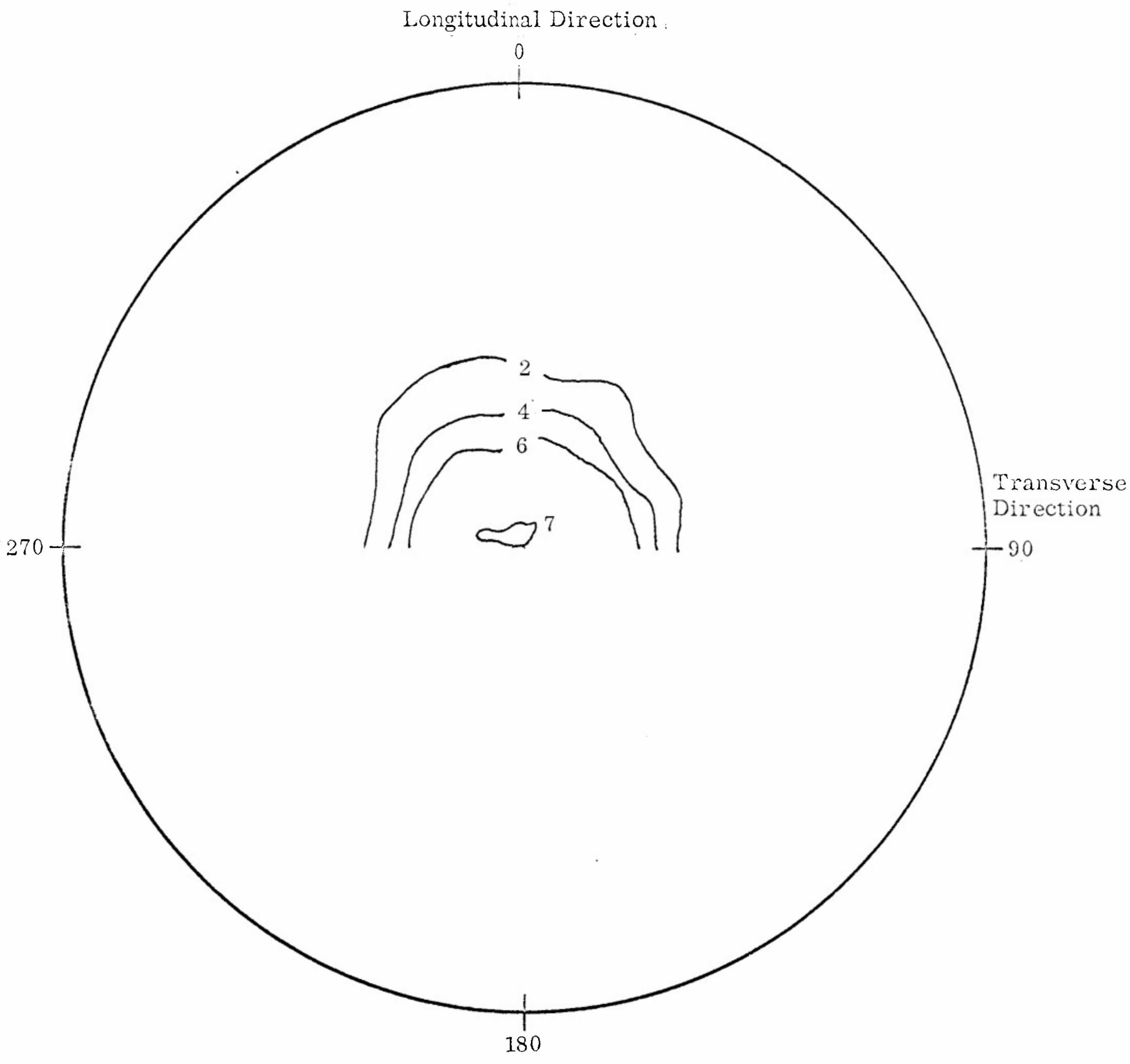


Fig. 35 Be (0002) Basal Pole Figure for Be-38% Al Sheet 21-31-2A
(Numbers represent intensities times random)

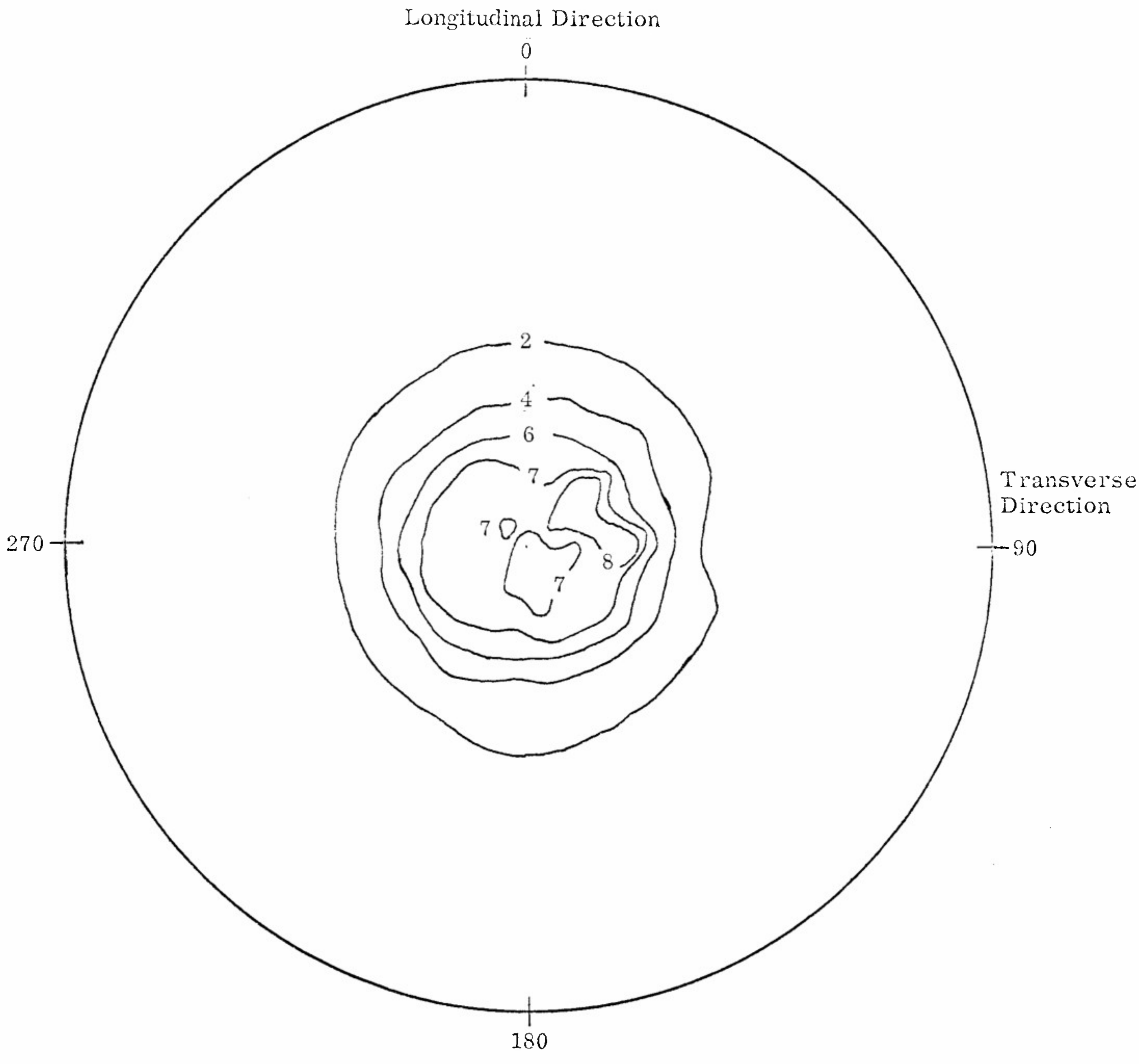


Fig. 36 Be (0002) Basal Pole Figure for Be-38% Al Sheet 21-34-300A
(Numbers represent intensities times random)

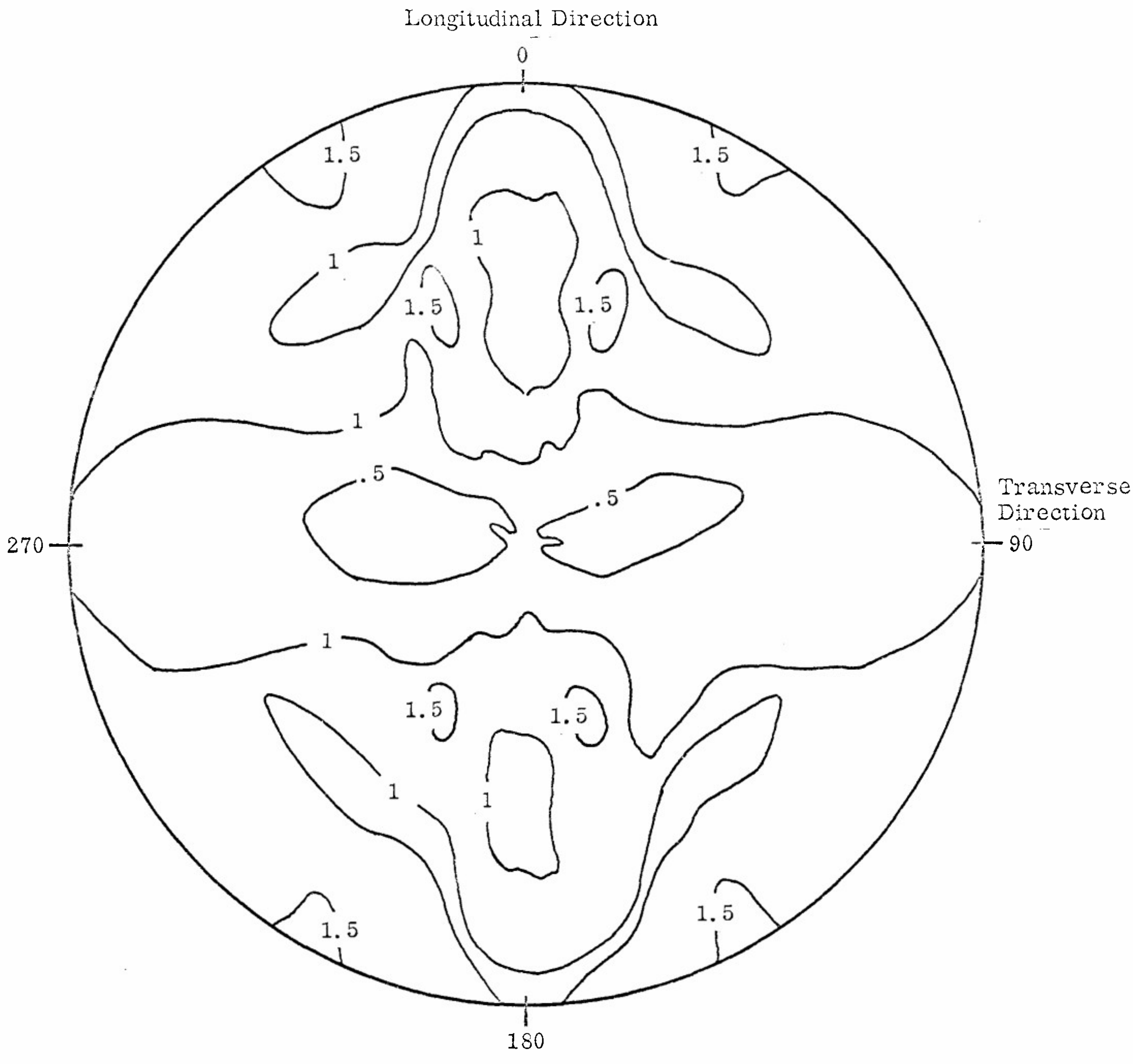


Fig. 37 Be (10$\bar{1}$1) Pyramidal Pole Figure for Be-38% Al Extrusion 21-33-5B
(Numbers represent intensities times random)

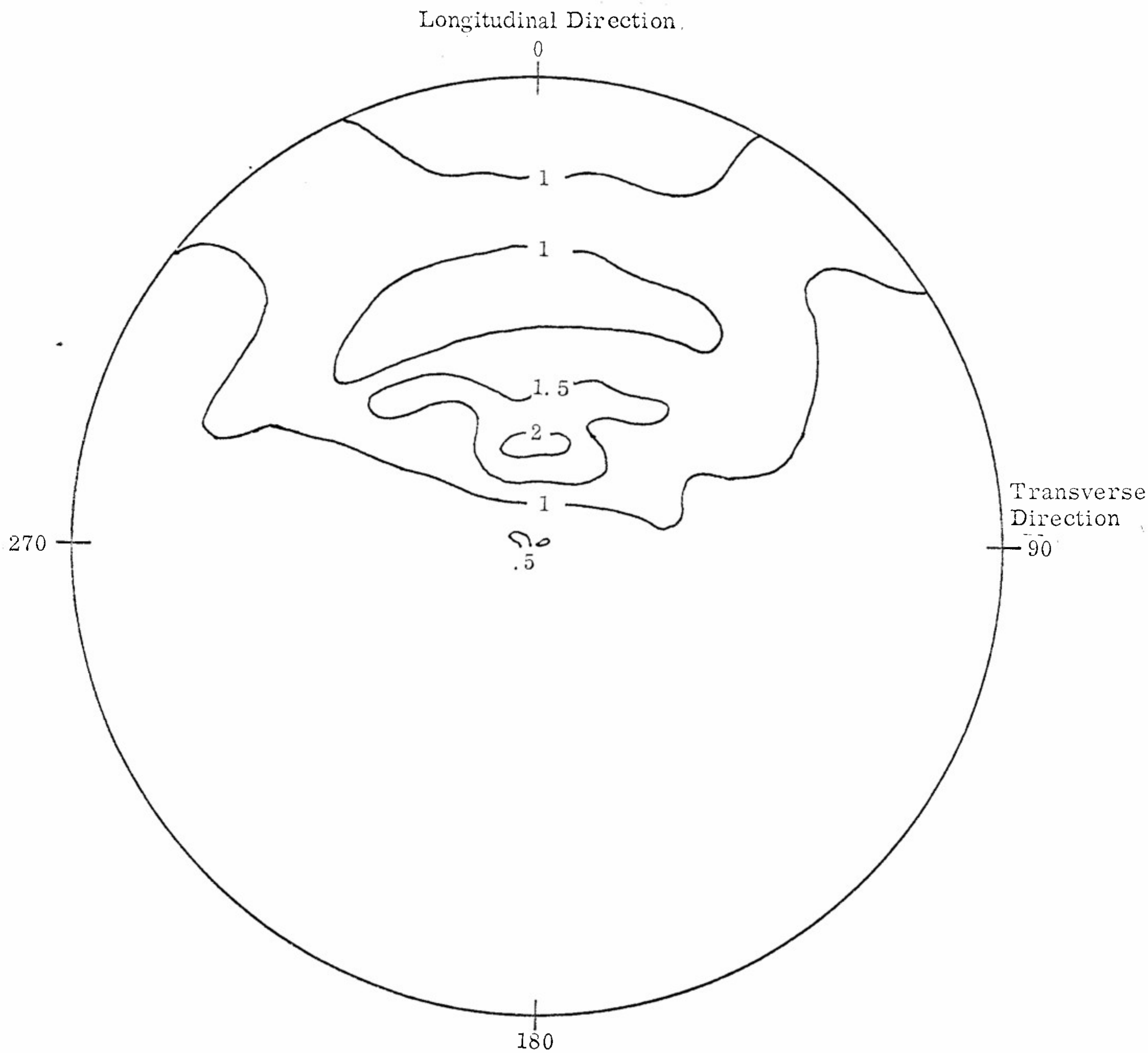


Fig. 38 Be (10$\bar{1}$1) Pyramidal Pole Figure for Be-38% Al Extrusion 21-32-8
(Numbers represent intensities times random)

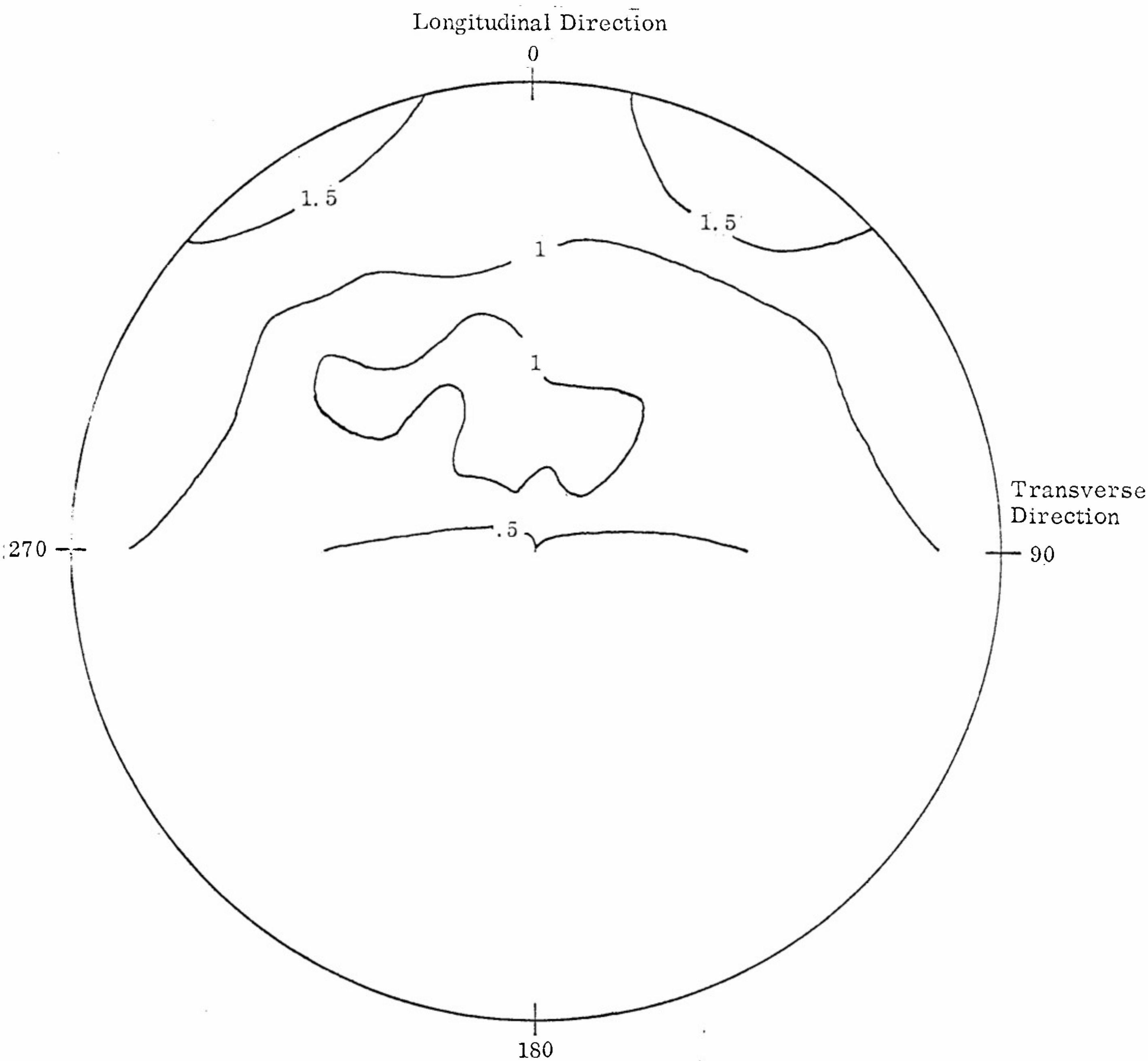


Fig. 39 Be (10$\bar{1}$1) Pyramidal Pole Figure for Be-38% Al Extrusion 21-35-307
(Numbers represent intensities times random)

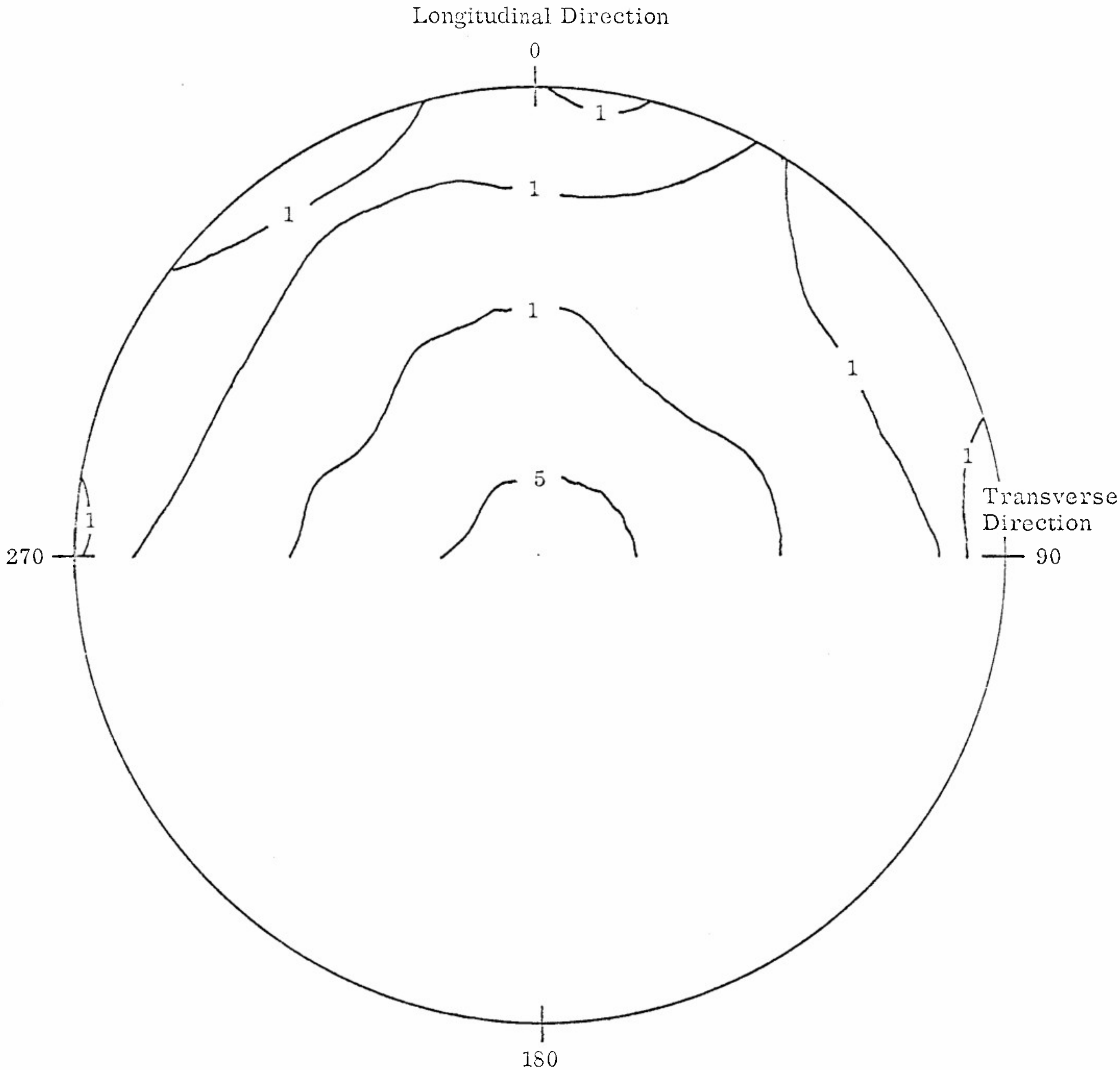


Fig. 40 Be ($10\bar{1}1$) Pyramidal Pole Figure for Be-38% Al Sheet 21-30-3B
(Numbers represent intensities times random)

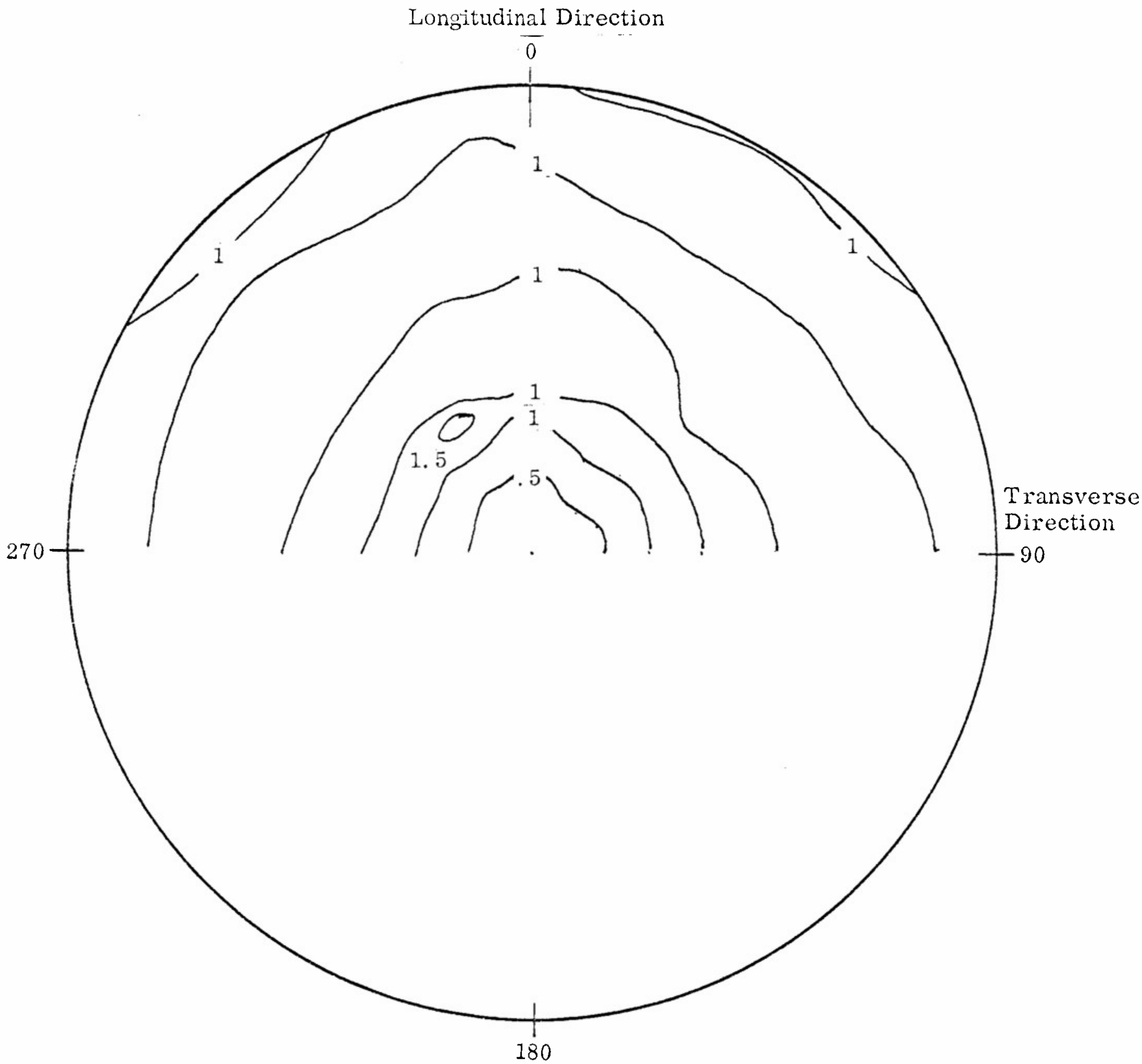


Fig. 41 Be (10$\bar{1}$1) Pyramidal Pole Figure for Be-38% Al Sheet 21-31-2A
(Numbers represent intensities times random)

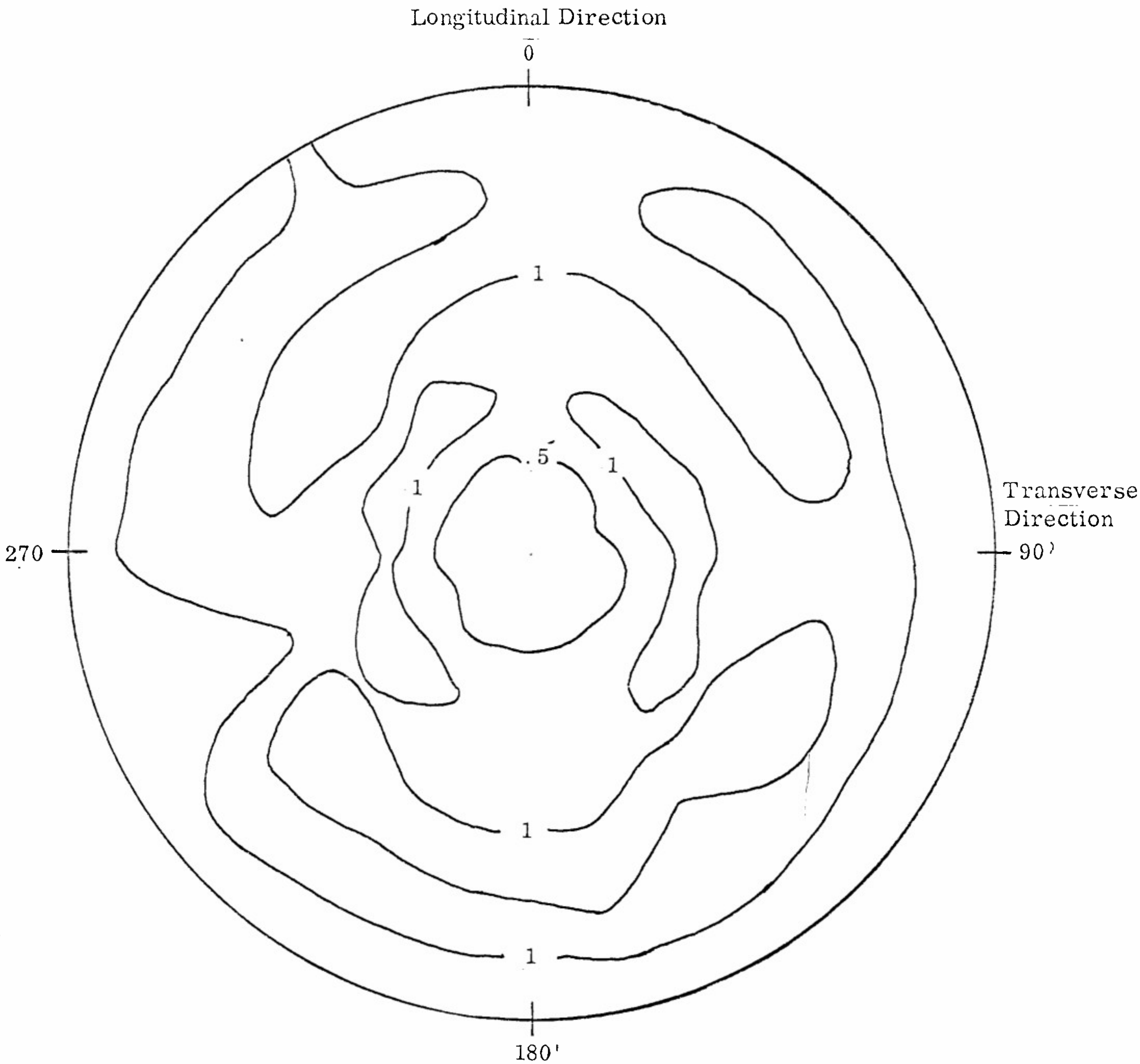


Fig. 42 Be (10$\bar{1}$1) Pyramidal Pole Figure for Be-38% Al Sheet 21-34-300A
(Numbers represent intensities times random)

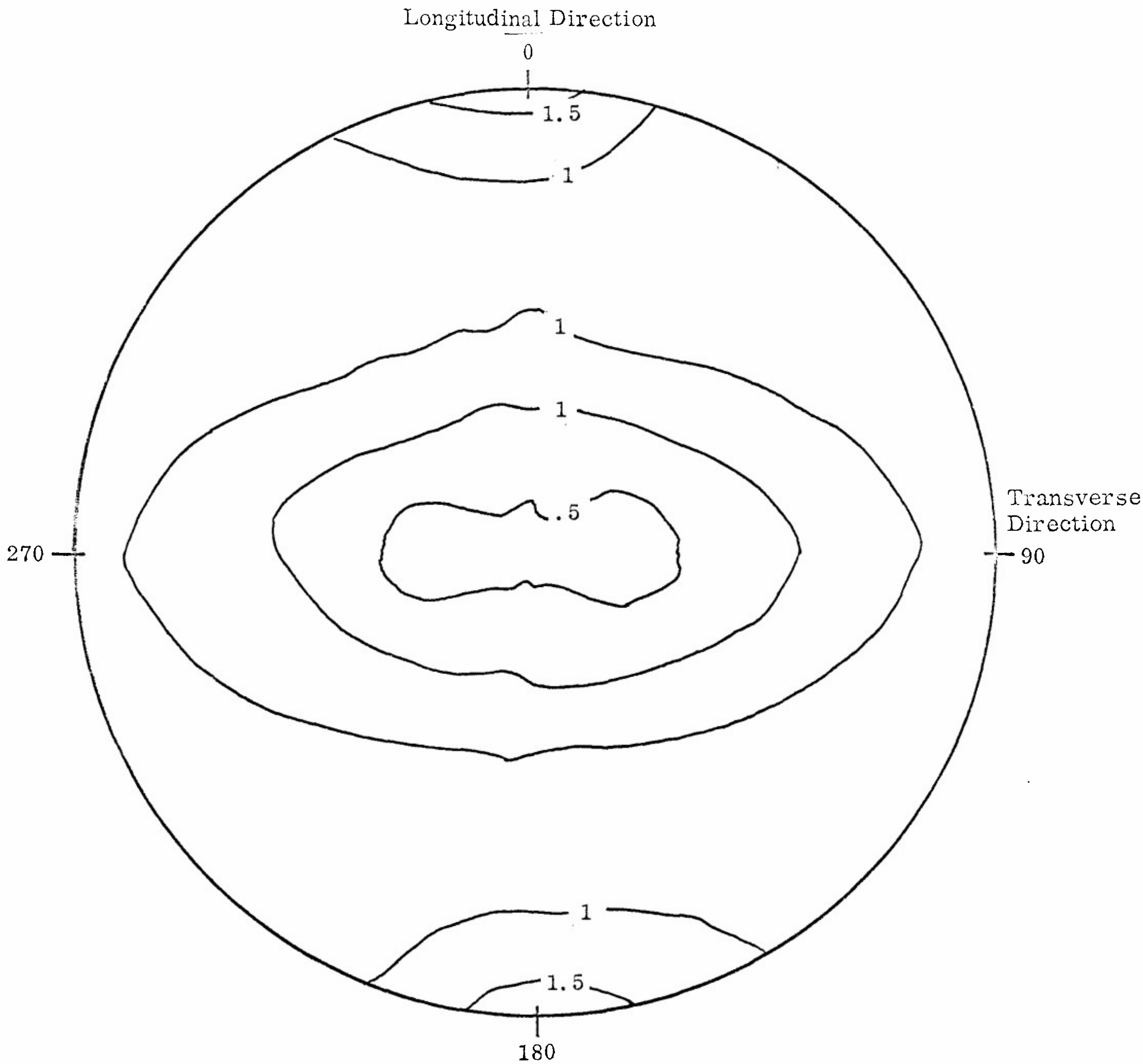


Fig. 43 Al (111) Pole Figure for Be-38% Al Extrusion 21-33-5B
(Numbers represent intensities times random)

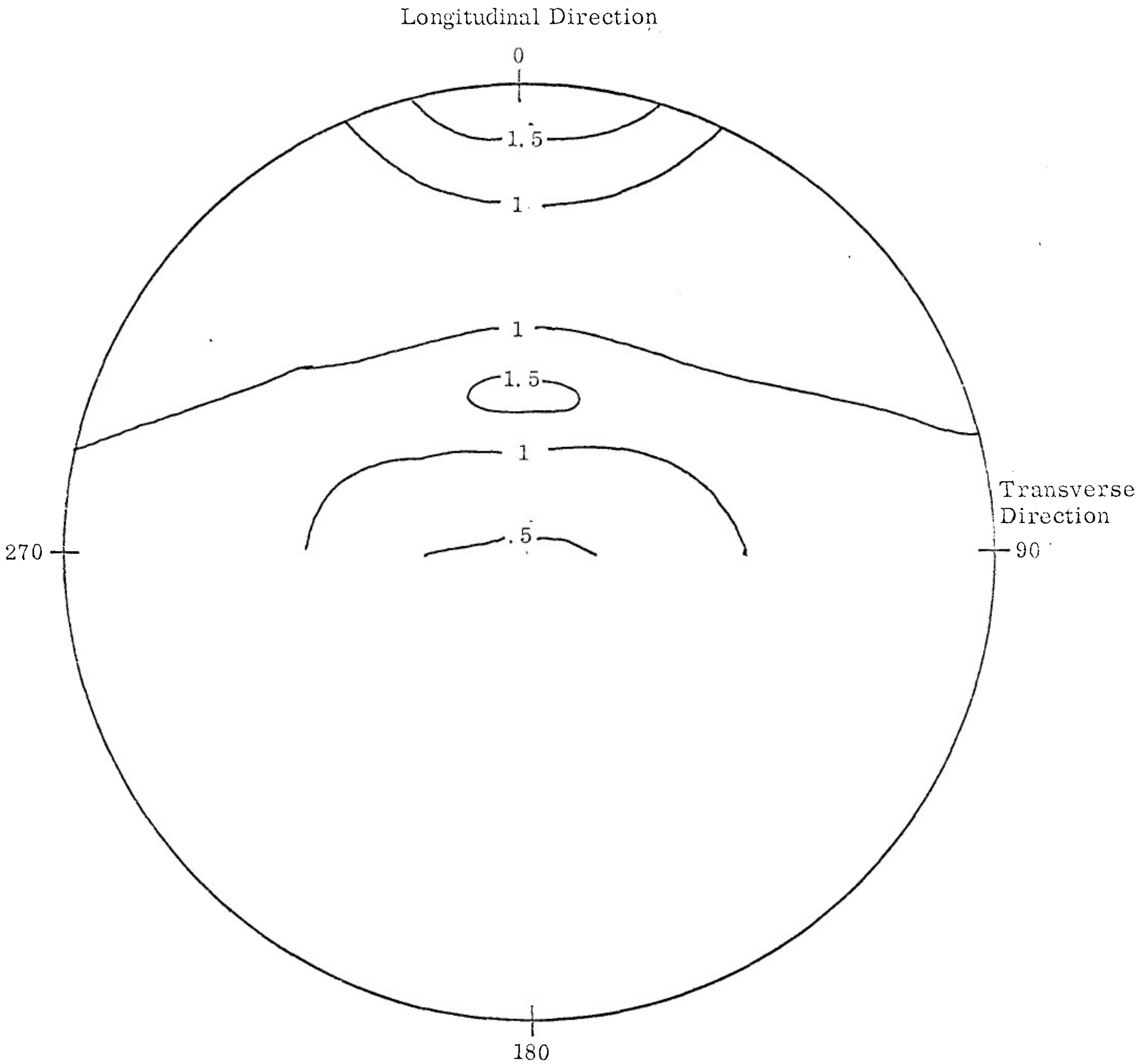


Fig. 44 Al (111) Pole Figure for Be-38% Al Extrusion 21-32-8
(Numbers represent intensities times random)

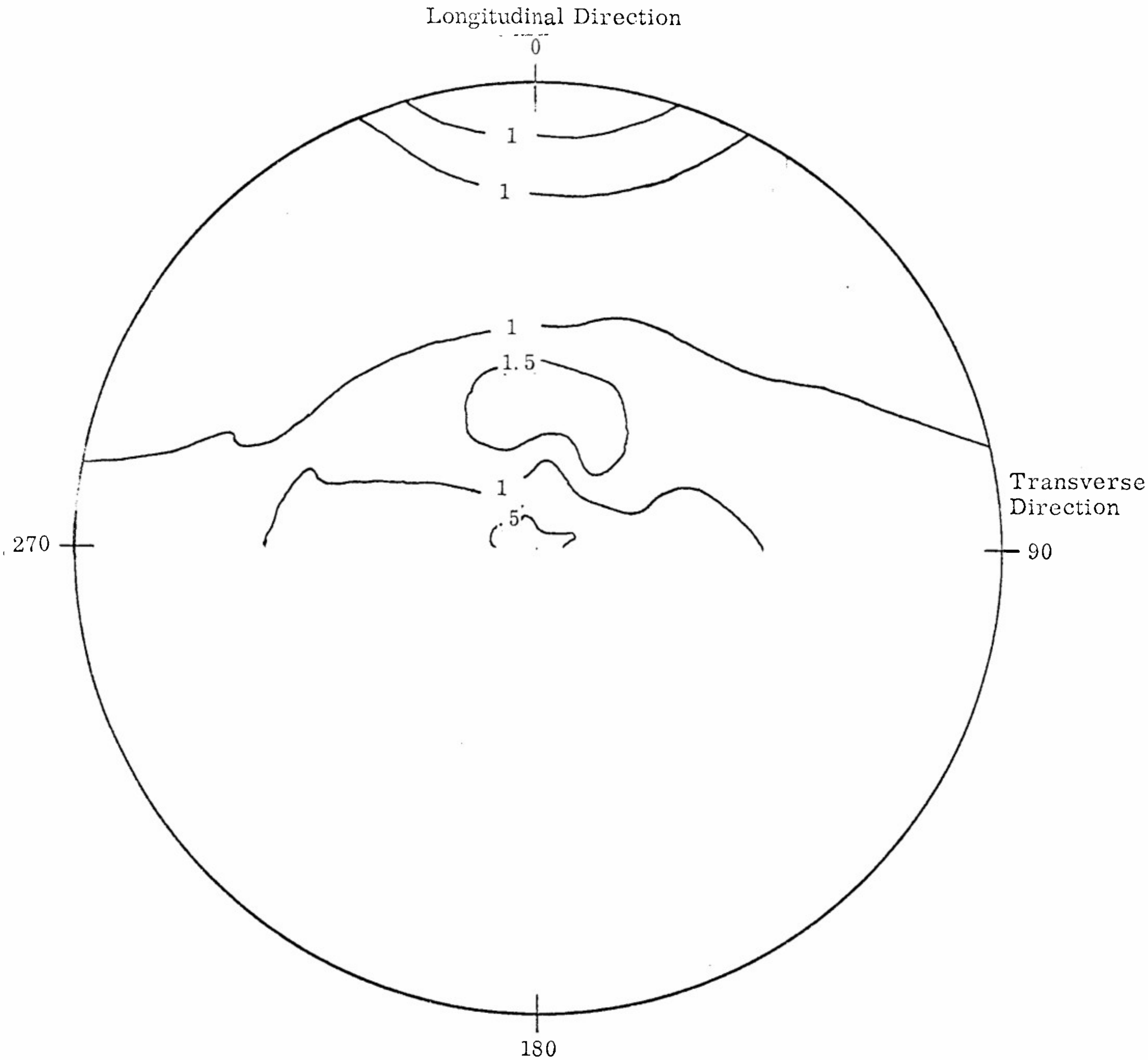


Fig. 45 Al (111) Pole Figure for Be-38% Al Extrusion 21-35-307
(Numbers represent intensities times random)

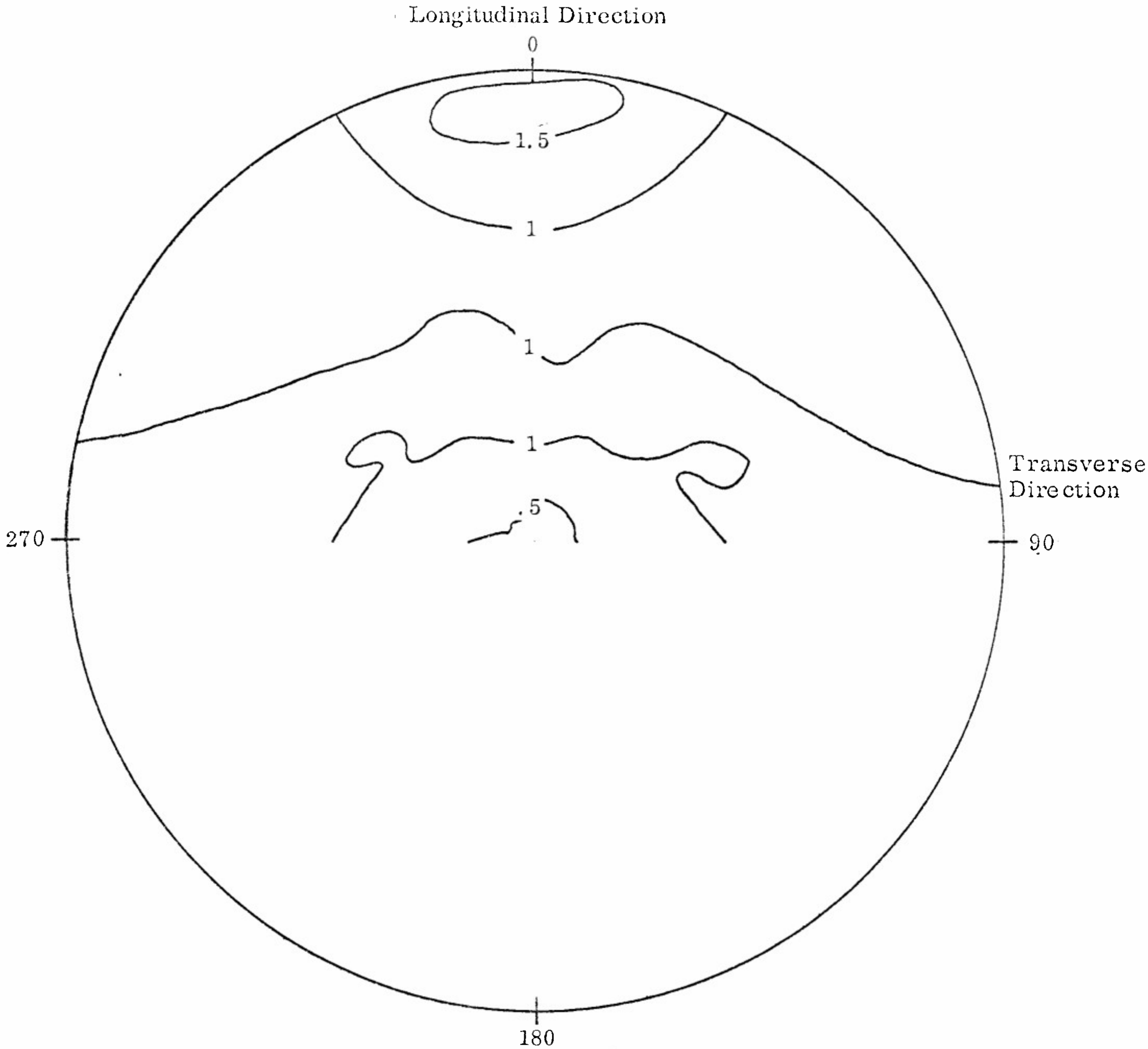


Fig. 46 Al (111) Pole Figure for Be-38% Al Sheet 21-30-3B
(Numbers represent intensities times random)

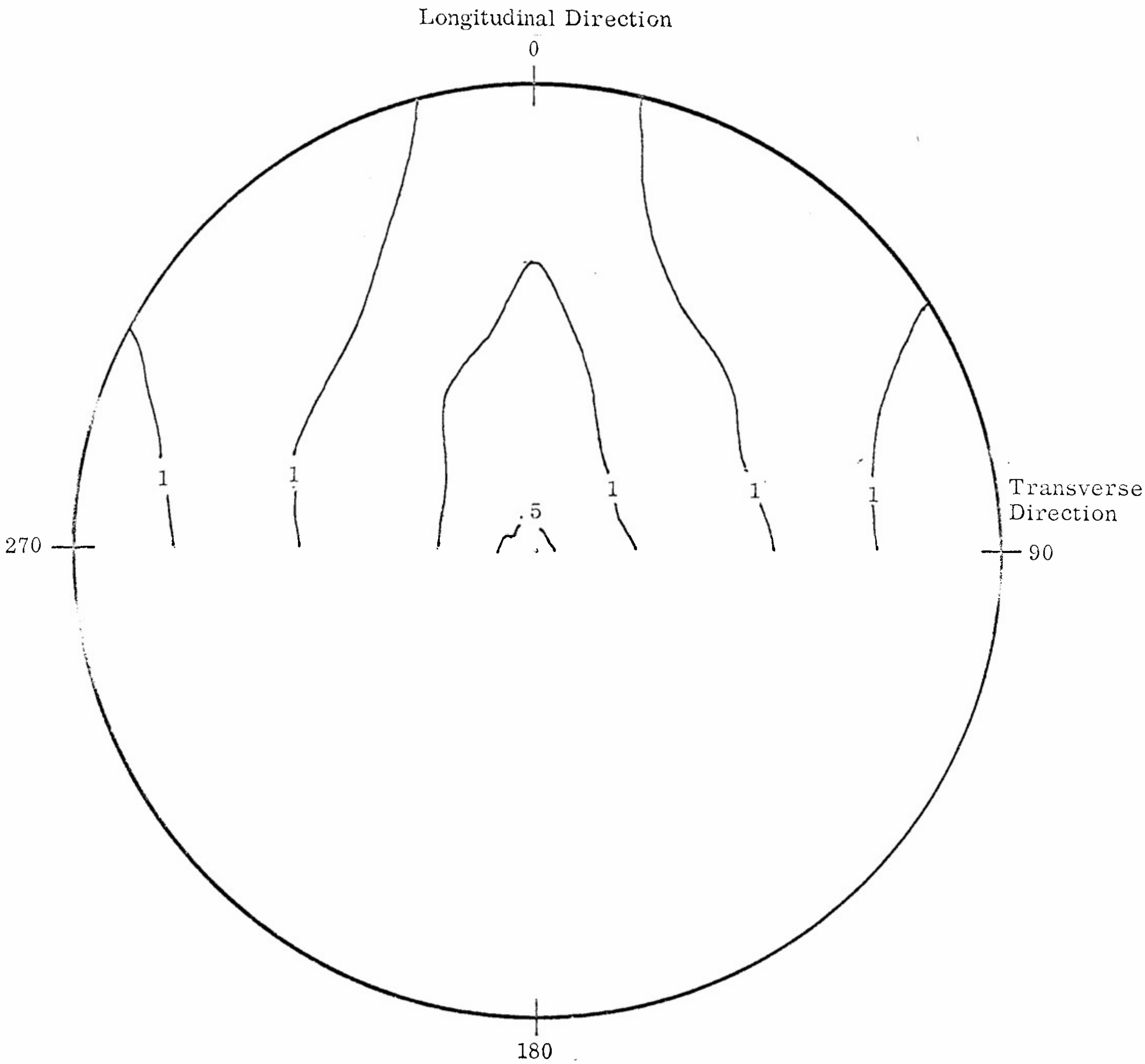


Fig. 47 Al (111) Pole Figure for Be-38% Al Sheet 21-31-2A
(Numbers represent intensities times random)

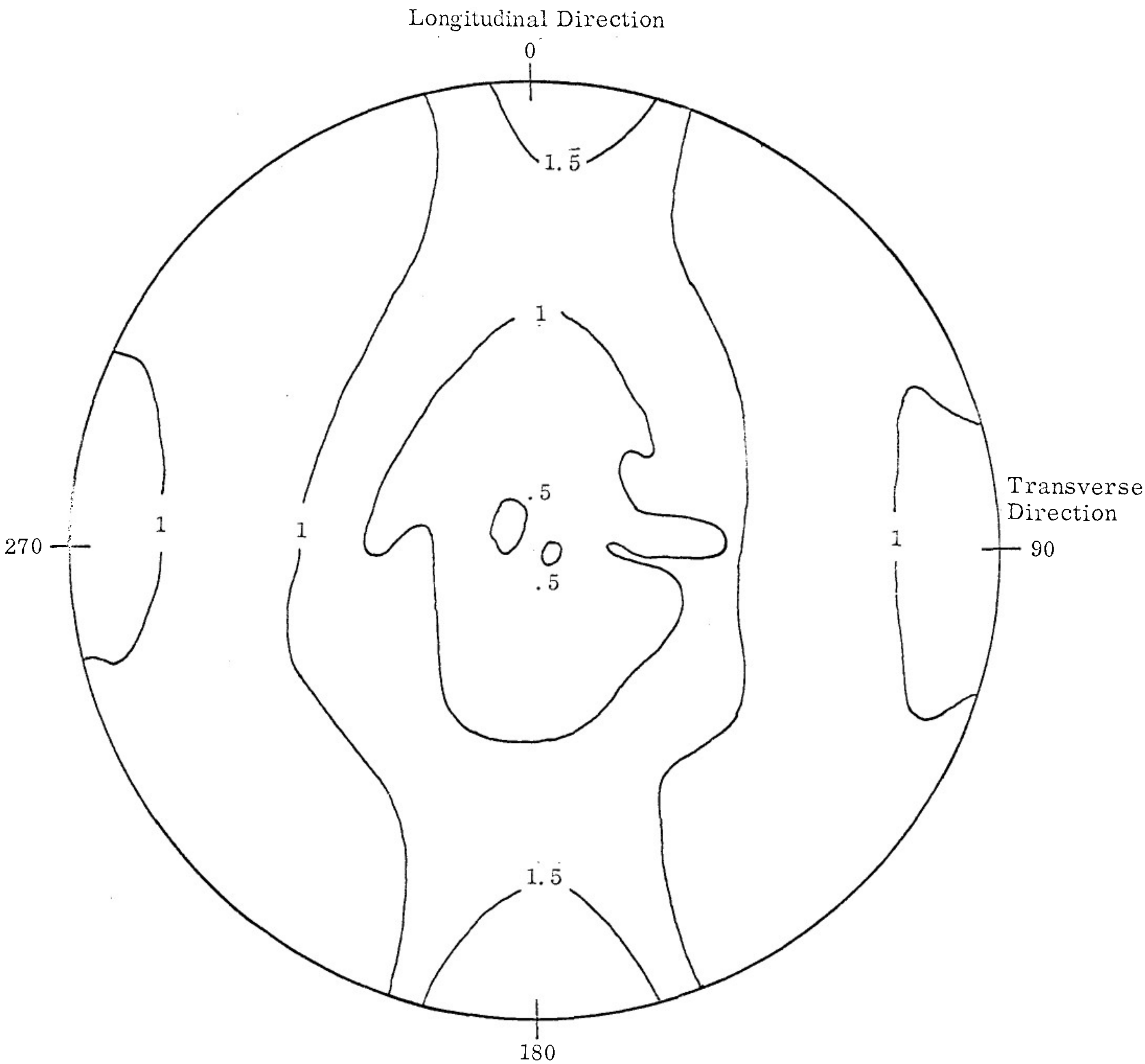


Fig. 48 Al (111) Pole Figure for Be-38% Al Sheet 21-34-300A
(Numbers represent intensities times random)

Appendix A

TEST TECHNIQUES

Appendix A
TEST TECHNIQUES

YOUNG'S MODULUS

Young's modulus was measured by loading the specimens in a Baldwin creep machine and using a Marten's type optical strain-measuring system with a strain sensitivity of 20 μin. /in. to provide accurate strain measurements. Strain was measured over a 3-in. gage length.

The Marten's measuring system was initially calibrated with a Tuckerman optical extensometer.

High temperature measurements were made in the same manner as room temperature tests by heating the specimen with a creep furnace having a Leeds and Northrup Speedomax temperature controller.

TENSILE TESTS

Room Temperature

Tensile tests were conducted at 75° F in a 10,000-lb capacity Instron testing machine using constant cross-head rates of 0.01 in. /min to approximately 1% strain and 0.1 in. /min from 1% strain to failure. This technique resulted in strain rates between the proportional limit and yield strength of approximately 0.005/min and 0.08/min prior to attaining the maximum load. Strain was measured with two microformer snap-on extensometers (ASTM Classification B-1) wired to provide electrical strain averaging. The gage length was 1 in. for all specimens except the transverse extrusion specimens which are 1/2 in.

Elevated Temperature

Elevated temperature tests were carried out in an identical manner to the room temperature tests. Specimens were self-resistance heated by a high amperage alternating current from an 18 kva Research Inc. power controller. Temperature was controlled at the specimen center to better than ±3°F by a Leeds and Northrup Speedomax temperature controller. Specimens were heated to test temperature in one minute and held at least two minutes before test.

The temperature gradient over the gage length of the specimen was a negative deviation from the control point of not more than 5%. Temperature gradients were monitored by a multipoint recorder receiving the output of thermocouples spot welded to the center and ends of the 1-in. gage length. All fractures occurred at the center of the specimen, and there was no significant relation between the spot welded control thermocouple and the fracture location.

Cryogenic

Tensile tests were made at -320°F by testing the specimens while immersed in liquid nitrogen. Specimens were immersed for at least 15 min before test. Strain was measured with a Baldwin Model PSH-8MS high-temperature extensometer (ASTM Classification B-1). All cryogenic tests were made in a 20,000-lb capacity Wiedemann-Baldwin Mark 20B testing machine. Cross-head rates were adjusted to give a strain rate of approximately 0.005/min to 1% strain and 0.08/min to failure.

ELEVATED TEMPERATURE EXPOSURE

Elevated temperature exposure tests were conducted in horizontal tubular air furnaces. Each furnace was equipped with recorder-controller instrumentation providing a continuous record of temperature. Daily temperature checks were made with a precision potentiometer.

The specimen configuration was identical to the 1-in. gage length tensile specimens. All specimen machining was completed prior to exposure so that any effects which might be produced by the cold work of machining were minimized.

COMPRESSION TESTS

Room Temperature

Compression tests were also conducted on the 10,000-lb capacity Instron testing machine using a constant cross-head rate of 0.01 in./min which results in strain rates of approximately 0.005/min. Strain was measured on the center 1-in. of the 2-in. long specimen by two Microformer snap-on compressometers wired to electrically average strain measurements obtained on opposite sides of the specimen.

Elevated Temperature

Elevated temperature tests were made in the same testing machine, using the same cross-head and strain rates as those for the room temperature tests. Test specimens were self resistance heated using techniques described by Fenn (Ref. 13) with an 18 kva Research Inc. power controller. Specimens were heated to temperature in 3 to 5 min and held for 3 to 5 min before testing. Temperature was controlled at the specimen center to better than ±5°F by a Leeds and Northrup Speedomax temperature controller. The temperature gradient over the gage length of the specimen was a negative deviation from the control temperature of not more than five percent. Temperature gradients were monitored by a multipoint recorder.

SHEAR STRENGTH TESTS

Room Temperature

Specimens were tested at 75°F in a 10,000-lb capacity Instron testing machine to determine the ultimate shear strength. A schematic drawing of Kaufman and Davies (Ref. 14) indicating the types of test, planes of shear, and loading directions is shown in Fig. 14.

Elevated Temperature

Elevated temperature tests were carried out on a 20,000-lb capacity Wiedemann-Baldwin Mark 20B testing machine using a split, front-opening air furnace for heating specimens. Furnace temperatures were automatically controlled by a Wheelco Type 402 indicating-temperature controller. Specimen temperatures were monitored using a thermocouple clamped to the specimen and a precision potentiometer; test temperature was controlled to better than ±3° F. Specimens were heated to test temperature in 25 to 35 min and held at temperature at least 5 min before test.

Test Specimens

Extrusions. Pin-type double-shear specimens, 1/8-in. in diameter, were tested to failure at a constant cross-head rate of 0.1 in./min. The fixture used was similar to that described in ASTM Specification B-316.

Sheet. Sheet single-shear type specimens were produced from sheet to the configuration indicated in Fig. 14 and tested to failure at a constant cross-head rate of 0.01 in./min.

BEARING STRENGTH TESTS

The technique utilized for bearing tests is similar to that described in ASTM Specification E-238. Tests at 75° F were made in a 10,000-lb capacity Instron testing machine at a constant cross-head rate of 0.01 in./min. Strain was measured with two microformer snap-on extensometers wired to provide electrical strain averaging. All elevated temperature bearing tests were made in a 20,000-lb capacity Wiedemann-Baldwin testing machine at a constant cross-head rate of 0.01 in./min. Test fixture design was such that the room temperature extensometers could be used. Specimen heating was accomplished using a split, front opening air furnace. Furnace temperature was automatically controlled and specimen temperature was monitored using a thermocouple clamped to the specimen and a precision potentiometer; test temperature was controlled to better than ±3° F. Specimens were heated to test temperature in one hour and held at temperature at least 10 minutes before test.

BEND ANGLE DETERMINATION

Bend specimens were produced having the dimensions 1-in. by 2-in. by 0.054-in. The uniform thickness for both sheet and extrusions was accomplished by use of a chemical etching process previously developed by LMSC. The specimens were bent at 75°F on a three-point loading jig having a 1-1/2-in. span and 0.25-in.-radius mandrel. A 500-lb capacity Instron testing machine was used to bend the specimens at a constant cross-head rate of 0.1 in./min. Bend tests were terminated immediately upon crack initiation as indicated by a drop in load on the autographic load-deflection plot.

Bend tests at elevated temperature were made in a Missimers oven equipped with a temperature controller. Specimen temperatures were read from a precision potentiometer and a thermocouple clamped directly to the specimen. Specimens were heated to test temperature in 15 min and held for 2 to 3 min before test; test temperatures were controlled to better than ±5°F. All other test techniques were identical to those used at room temperature.

Bend tests at - 320° F were made with the specimen totally immersed in liquid nitrogen; the specimens were immersed for 5 to 10 min before test. Other techniques were identical to those used at room temperature.

X-RAY TECHNIQUE FOR PREFERRED ORIENTATION

A circular specimen 1-in. in diameter was ground to the calculated optimum thickness of 0.01 in. It was then etched in cold NaOH to remove any aluminum which had been smeared over the surface during grinding. The specimen was mounted in a General Electric automatic pole figure goniometer used in conjunction with a General Electric XRD-5 diffraction unit. A beam slit of 0.4 deg and a 0.2-deg receiver slit were used to resolve the Be (0002) and Be $(10\bar{1}1)$ diffraction lines in transmission with Ni filtered Cu $K\alpha$ radiation. A 1.0-deg beam slit and a 0.1-deg receiver slit were used in all other cases. Measurements were made in transmission using the technique of Decker, Asp, and Harker (Ref. 15) and a modified Shulz technique (Ref. 16) was used in reflection. Recorded intensities were corrected for absorption and normalized to a random

basis following the method described by Bragg and Packer (Ref. 6). In both the transmission and reflection techniques, a limiting value of α occurs due to interference of the specimen holder with the diffracted beam. The "blind" region created by this limitation was covered in the aluminum pole figure by measuring the (111) diffraction line in transmission and the (222) diffraction line in reflection. Ni-filtered Cu Kα radiation was used to record both lines. Low intensity precluded the use of second order lines in determining the beryllium textures. For this reason, radiation of different wave lengths was used to record the same lines. Va-filtered Cr Kα was used in reflection and Ni-filtered Cu Kα in transmission.

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